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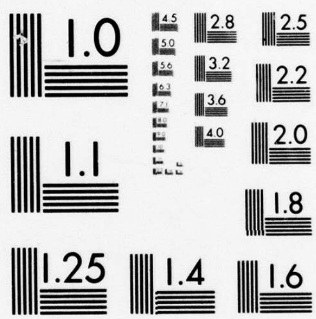
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INVESTIGATION OF MODULATION/CODING TRADE-OFF FOR MILITARY SATELLITE COMMUNICATIONS.

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J. K. Omura,
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This final report presents the analysis, computer program documentation, and results of a modulation/coding tradeoff study of satellite communication systems. Performance measures of bit error rates and data bit throughput are evaluated for coherent MPSK signals through bandlimited nonlinear satellite repeaters with uplink and downlink noise.

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ACKNOWLEDGMENT

The authors wish to acknowledge the role which Dr. Pravin Jain, Satellite Communication Branch, Defense Communication Agency has played in defining and motivating the complex satellite communication problem treated herein. His past works have served as the springboard for carrying out this investigation.

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TABLE OF CONTENTS

1. INTRODUCTION

The Final Report on INVESTIGATION OF MODULATION/CODING TRADE-OFF FOR MILITARY SATELLITE COMMUNICATIONS performed for the DEFENSE COMMUNICATION AGENCY under Contract No. DCA100-76-C-0062 and directed by Dr. Pravin Jain is presented in four volumes: Volume I - Summary, Volume II - System Modeling and Analysis, Volume III - Appendices, and Volume IV - Computer Programs Manual. This document is Volume I and it presents a summary of the work accomplished in this study during the 12 month period 19 July 1976 through 19 July 1977.

2. PURPOSE

The purpose of this study is to investigate modulation, demodulation, and coding techniques to achieve maximum data throughput over nonlinear, bandlimited satellite repeaters for fixed data bit error rates. These techniques include single and multiple coherent MPSK signals sent through the satellite repeater, memoryless and maximum likelihood Viterbi demodulators, and a coding analysis based on computational cutoff rates.

With the growing demand for satellite communications within the DoD at both UHF and SHF frequencies, the efficient use of available satellite power and bandwidth is beoming increasingly important. Since the trend now is toward greater available power the increased demand for satellite communications places a new emphasis on more efficient utilization of available bandwidth. This study is directed toward

techniques for achieving maximum throughput in bits/second/ Hertz over given available satellite channel bandwidths. A unique feature of this study is the inclusion of nonlinear satellite TWT characteristics, which create signal distortion and intermodulation effects, together with a computable throughput parameter that measures achievable data rates as a function of all the basic parameters of the satellite communication systems. This includes the computation of error rates so that the primary criterion for comparing the performance of various techniques is the achievable data throughput for given fixed data error rates. Among these techniques are some unconventional notions such as deliberately creating intersymbol interference and co-channel interference to increase total throughput over the satellite repeater and then using maximum likelihood demodulation and coding to reduce the error rates.

The overall objective of this study is to determine the modulation, demodulation, and coding trade-offs that achieve maximum data rate through a nonlinear satellite repeater for given data bit error probabilities. This includes the effects of soft limiters and TWT characteristics in the assumed satellite repeater model. To achieve this goal the first half of this study concentrated primarily on the difficult problem of evaluating uncoded symbol error probabilities and transition probabilities for the modulation/demodulation technique of interest. The second half of this study concentrated on techniques for combatting intersymbol interference and the

analysis of multiple FDMA signals in the satellite communication system. A coding analysis was superimposed on each of these cases by examining the coding channel created by the modulation to demodulation (including intersymbol interference rejection algorithms) parts of the communication system. Then for a given satellite repeater (which includes as parameters uplink and downlink signal to noise ratios, filters, limiter and TWT nonlinearities and TWT backoff) and for a fixed data bit error probability a comparison of the achievable data rates for each of the modulation/demodulation techniques with and without algorithms for combatting intersymbol interference and with and without coding techniques can be made.

3. BACKGROUND

Here a brief discussion is given of some background and earlier works that have had a direct influence on this study and have provided insights into the problem of sending data over a coherent satellite communication system.

Finding a parameterized mathematical model for the nonlinear satellite repeater requires a balance between accurately representing real satellite systems and analytical tractability. The mathematical models of this study are based for the most part on the works of Jain (References 1,2), Jain, Hatfield, and Leung (Reference 3), and Jain and Blachman (Reference 4). These works also suggested useful approaches to finding symbol error probability expressions. The fundamental work of Blachman (Reference 5) is basic to our under-

standing of the characterization of the TWT in the satellite repeater. The multiple signal FDMA problem especially requires a deeper understanding of the relationship between the measured zonal output response of a memoryless nonlinearity with a narrowband input signal to the actual voltage response with any input signal.

Most design and analysis of communication systems consider separately the modulation/demodulation technique and the coding technique in a communication system. Usually a modulation/demodulation technique is evaluated on the basis of symbol error probability without considering how this influences the overall performance with coding. When coding is being considered, in most cases the modulation/demodulation technique is already fixed. This kind of separation has often led to situations where the modulation is chosen so that there is little chance for any effective coding gain. When coding is to be employed, Wozencraft and Kennedy (Reference 6) and more recently Massey (Reference 7) have emphasized the point that the choice of the modulation/demodulation technique ought to be based on providing a good coding channel and not on the uncoded symbol error probability. Indeed, it is often the case that the overall system performance with coding is better with modulation/demodulation techniques with larger symbol error probabilities. In fact the symbol error probability of a modulation/demodulation technique already implies a "hard" decision at the demodulator output whereas from a coding point of view the demodulator output ought to be quantized to more

levels resulting in a "soft" decision demodulator output (Reference 7). This can result in 2 dB improvement with 3 bit quantization of the demodulator output for BPSK modulation over the AWGN channel. In this study the approach suggested by these papers was taken and for each modulation/demodulation technique the evaluation of the expression for the computational cutoff rate was implemented in computer programs. These coding parameters are used in the overall modulation/coding tradeoff analysis.

4. OVERALL APPROACH

The satellite communication system (see Figure 1) has many variables that influence the overall performance. In order to examine tradeoffs in the design of the system this study examined the overall performance for many combinations of these variables. One of the objectives is to develop a better understanding of how all these variables interact and influence error probabilities and data rates. It is clear from the outset that real time computer simulations would be too costly and would not satisfy this objective.

The approach in this study has been to carry out the mathematical analysis of the satellite communication system as far as possible before employing a computer and when computers are used it is for the evaluation of mathematical expressions of various performance measures and not for real time simulation. The analytical expressions can often show directly how variables of the satellite communication system

influence the overall performance. Any mathematical analysis, of course, depends directly on the mathematical model used for the satellite communication system. Here a balance of the choice of parameterized mathematical models must be made between realistically representing real system and requiring that they are amenable to mathematical analysis. It is felt that the models used here satisfy these often conflicting requirements. In general simplifying assumptions on the mathematical model still capture the major effects of the system variables and we have confidence in the relative effects of the variables on the overall performance measures.

5. RESULTS OF THIS STUDY

Most of the results of this study are computer programs that evaluate the performance of single and multiple coherent MPSK signals sent over nonlinear, bandlimited satellite repeaters with both uplink and downlink noise as shown in Figure 1. Basic to this study is the introduction of a new throughput criterion which evaluates the achievable information throughput in bits per second per Hertz for the general satellite repeater models when various MPSK modulations, signaling times, and coding techniques are employed. Memoryless and Viterbi demodulators were also evaluated according to this achievable throughput criterion. This was done for the single channel (TDMA) and partly extended to the FDMA channel. Computer programs implementable on the DCEC computer that provides an analytical simulation of system performance achievable have been developed. They are capable of evaluating the

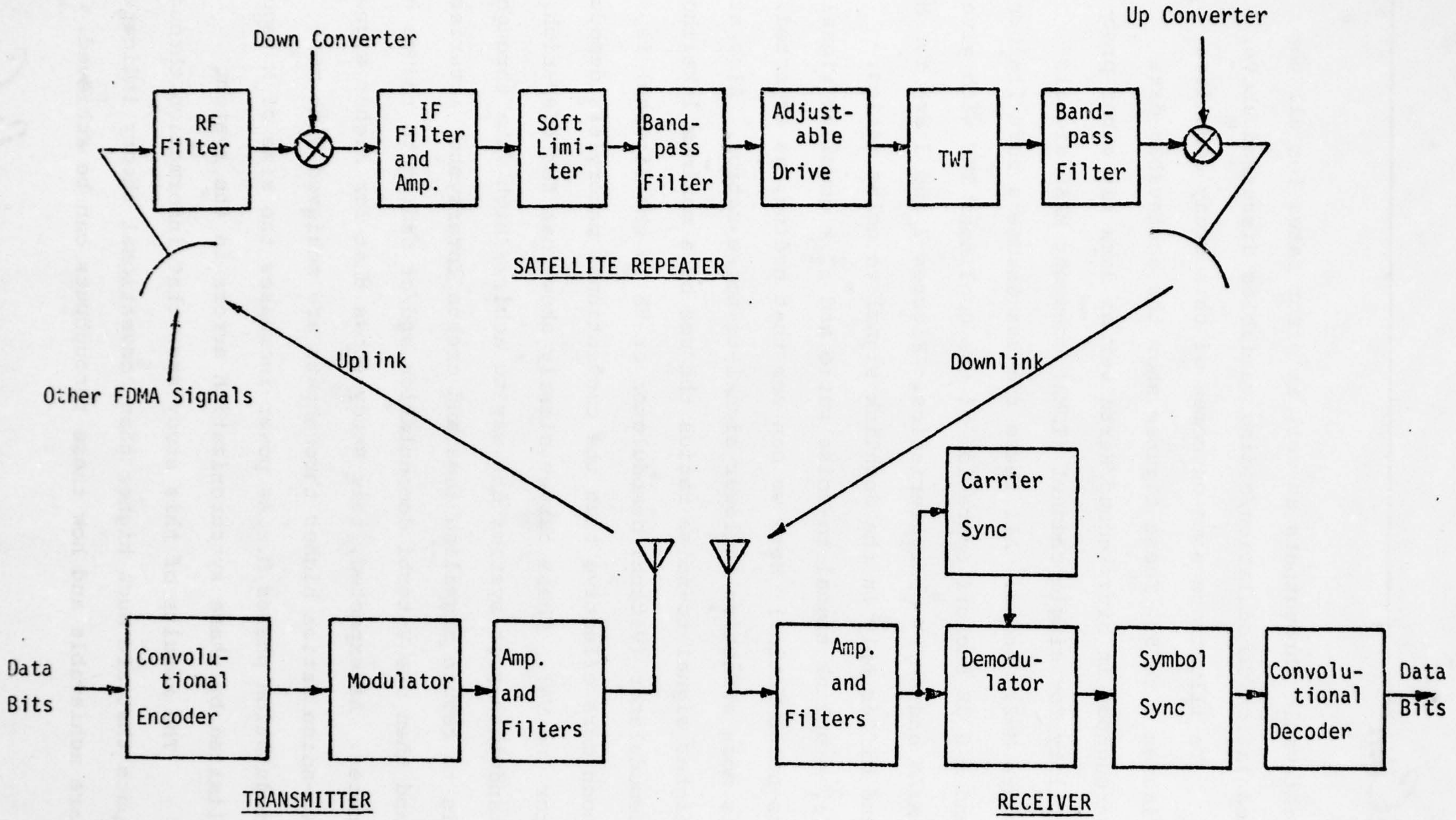

Figure 1 Satellite Communication System

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achievable throughputs as well as error rates for all the modulation/demodulation/coding variables discussed above.

To illustrate some outcomes of this study consider Figures 2 to 5. These figures show the achievable data throughput in bits/second/Hertz versus data bit error probability for single channel (TDMA) coherent MPSK signals where M=2,4 and 8. All these figures assume a soft limiter and a 0 dB backoff operation of the nonlinear TWT with given AM/AM and AM/PM characteristics. Figures 2 and 3 are for M=2 and differ only in the downlink signal to noise ratios. (ρ_1^2 = uplink signal-to-noise ratio and ρ_2^2 = downlink signal-to-noise ratio.) Here we can see that coding, as expected, is more effective at lower signal-to-noise ratios. Also at higher signal-to-noise ratios the use of a maximum likelihood demodulator (Viterbi demodulator or VA in the figures) is much more effective than the conventional memoryless demodulator (no VA). These curves clearly show that for EIRP-rich, bandwidth-poor systems one way to achieve high data throughput is to reduce signaling time and create intersymbol interference and then use Viterbi demodulation and/or coding to reduce error rates. As expected, this study shows that for higher signal-to-noise ratios higher throughputs are achieved with more modulation phases M. As power increases the size of M becomes limited by phase synchronization errors in the system.

The results of this study show that information throughputs that are much higher than conventional theory indicates are achievable and how these throughputs can be achieved.

Figure 2. Data Bit Throughput vs. Error Rate

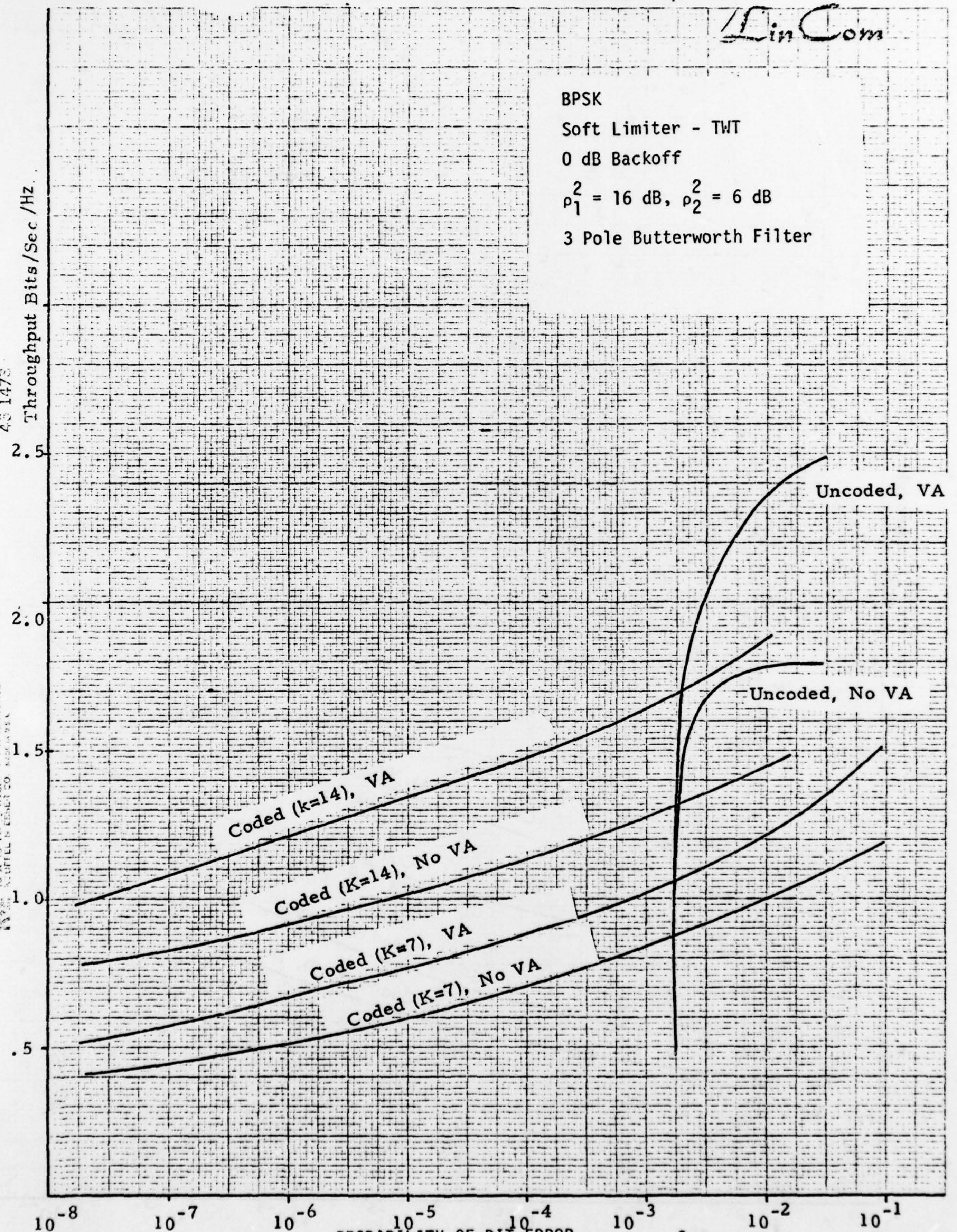


Figure 3. Data Bit Throughput vs. Error Rate

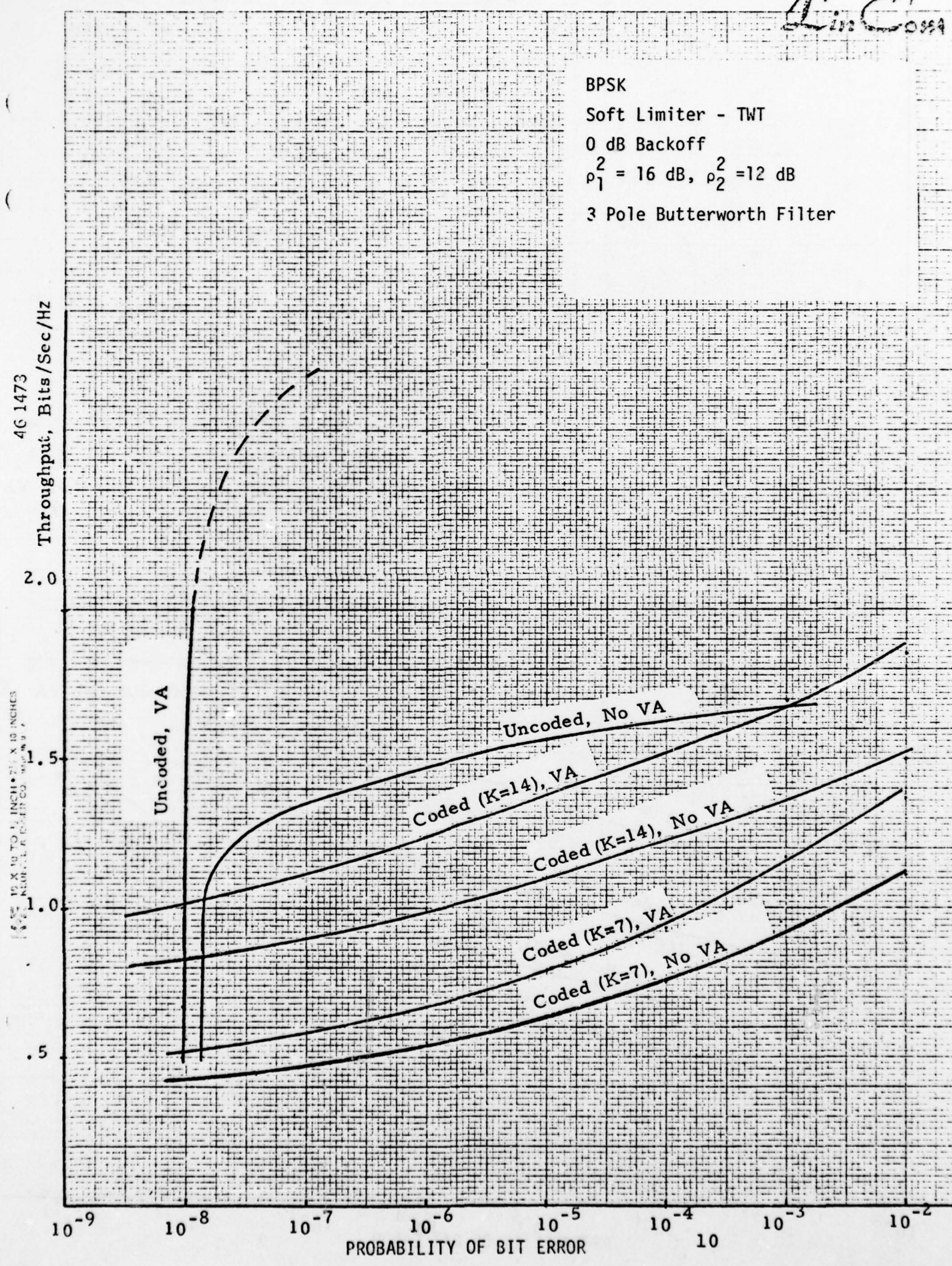


Figure 4. Data Bit Throughput vs. Error Rate

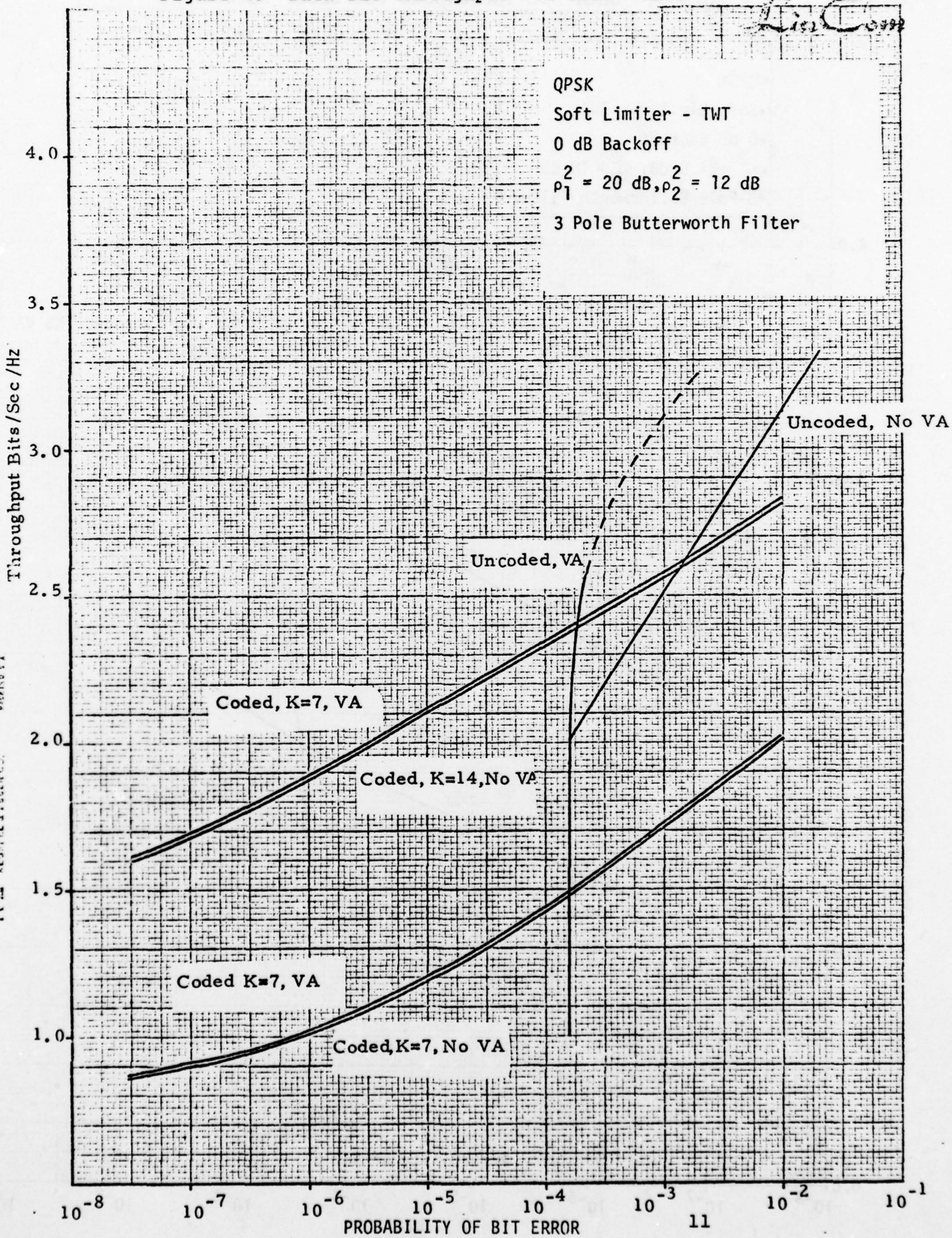
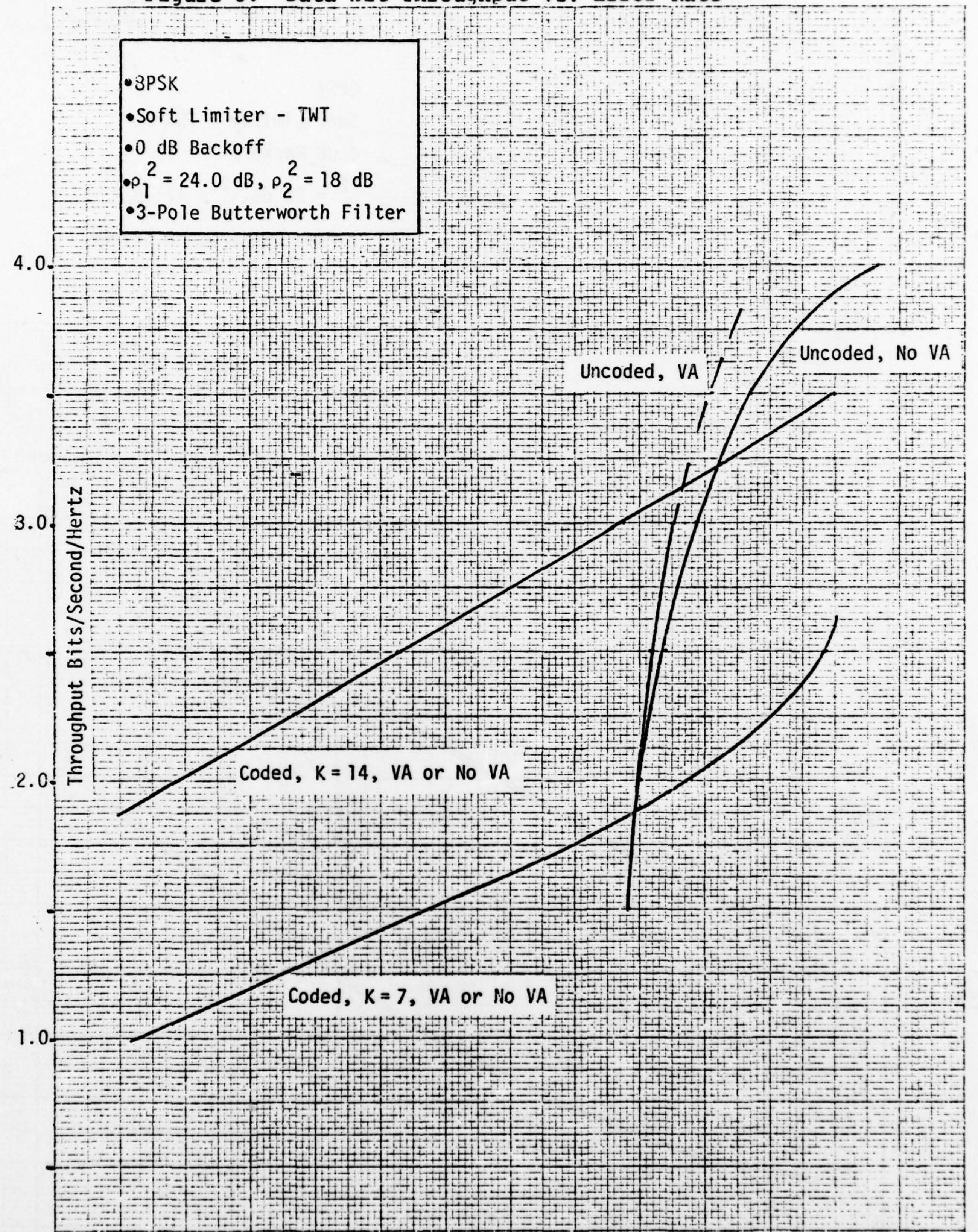


Figure 5. Data Bit Throughput vs. Error Rate



Normally when there is a fixed bandwidth, there is a limited maximum symbol rate limit without creating intersymbol interference. If the symbol rate is increased further the resulting intersymbol interference degrades performance. One can use coding techniques to reduce this increased symbol error rate due to intersymbol interference but coding causes a corresponding reduction of information throughput. Using the throughput parameter, this study shows clearly the maximum achievable information throughput with coding. The outcome of this study show that there is an optimum symbol signalling time which often results in some intersymbol interference which can be combatted effectively with a Viterbi demodulator and coding.

In the following we present more details to this study and show how the data throughput versus data bit error rates of Figures 2 to 5 can be obtained for the satellite communication system of Figure 1.

Characterization of the Satellite Communication System

The model for the satellite communication system is shown in Figure 6 when there is a single MPSK signal. With multiple FDMA signals the main difference is the existence of other signals at the input to the satellite repeater bandpass filter and the use of integrate and dump receivers that are approximated as the receiver shown in Figure 6 with multiple samples per signalling interval. The satellite repeater memoryless nonlinearity consists of a cascade of a

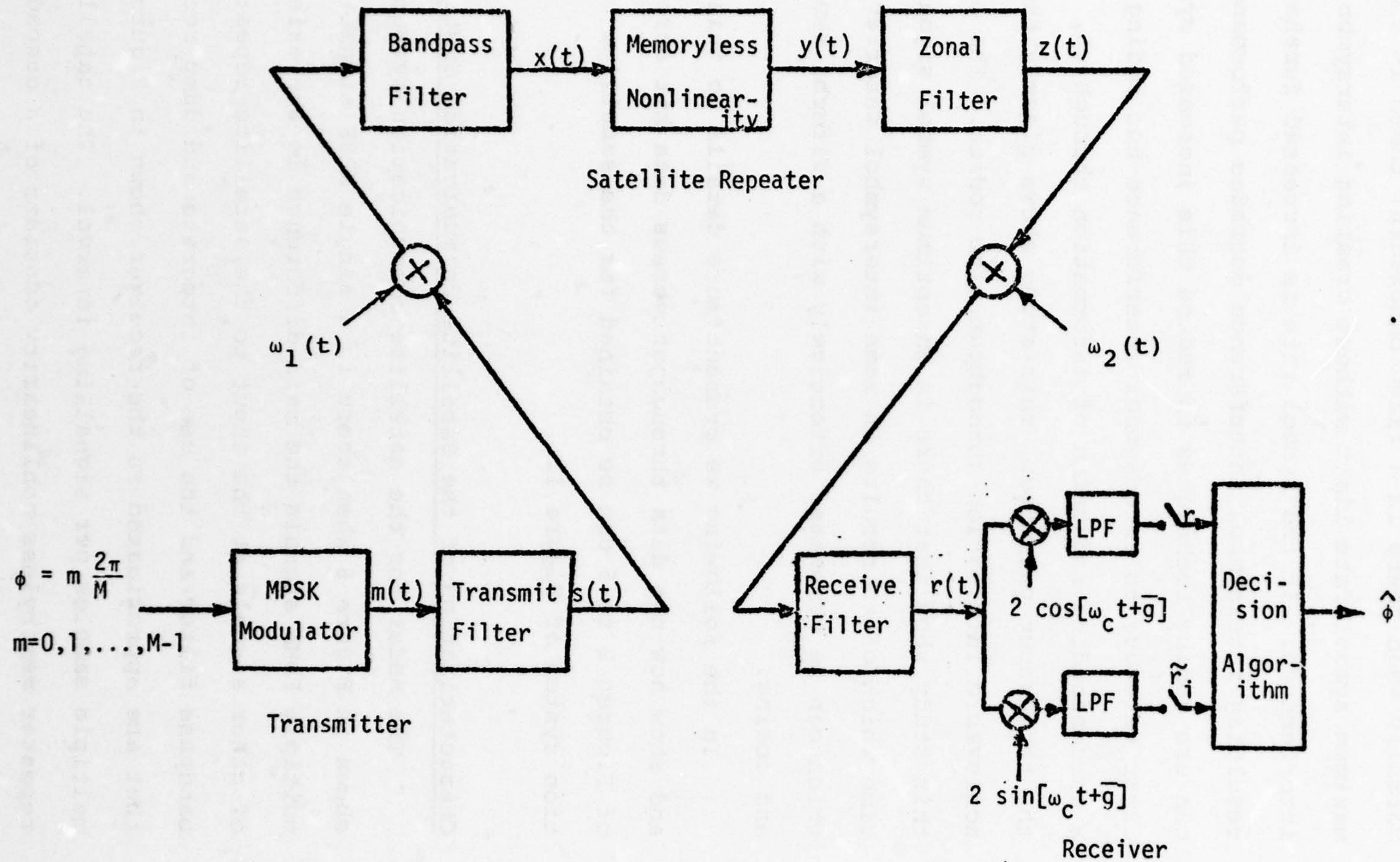


Figure 6. Model for the Satellite Communication System

soft limiter and a TWT amplifier. A typical power transfer characteristic of a soft limiter is shown in Figure 7 and a typical measured TWT characteristics are shown in Figure 8. These two memoryless nonlinear devices were used as an example in the computer outputs presented in this final report.

Only the transmit filter is allowed to create intersymbol interference. Typical envelope responses of transmit IF Butterworth filters are shown in Figure 9 for N=3,5 and 13 poles. The computer programs include both Butterworth and Chebyshev filters which have double sided 3 dB bandwidth denoted B. For MPSK signals of duration T seconds the major intersymbol interference parameter is the product BT which in this study range from 0.4 to 2.0.

The receiver observables consist of in-phase and quadrature samples of the low pass filtered baseband signal received from the satellite downlink channel. These observables are then inputs to a decision algorithm which can be memoryless or a maximum likelihood sequence estimation algorithm when there is intersymbol interference. This maximum likelihood estimation can be realized as a Viterbi algorithm and is referred to as a Viterbi demodulator. This had first been shown by Forney (Reference 8) and Omura (Reference 9).

Uncoded Symbol Error Rates With Memoryless Demodulators

For the satellite communication system model of Figure 6, the uncoded symbol error probabilities for MPSK signals and a memoryless demodulator were first computed. When there is

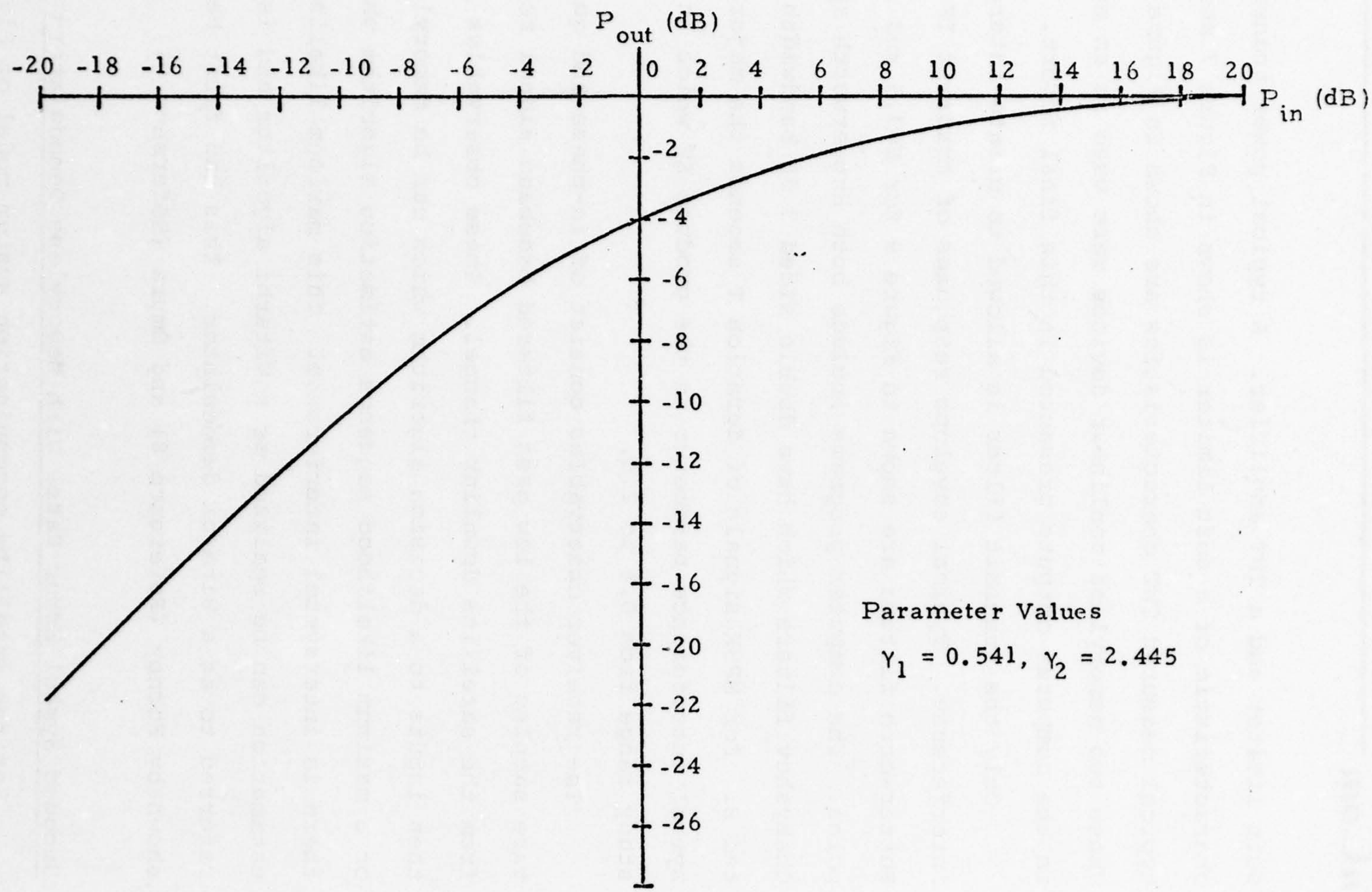


Figure 7. Power Transfer Characteristics of the Limiter Model

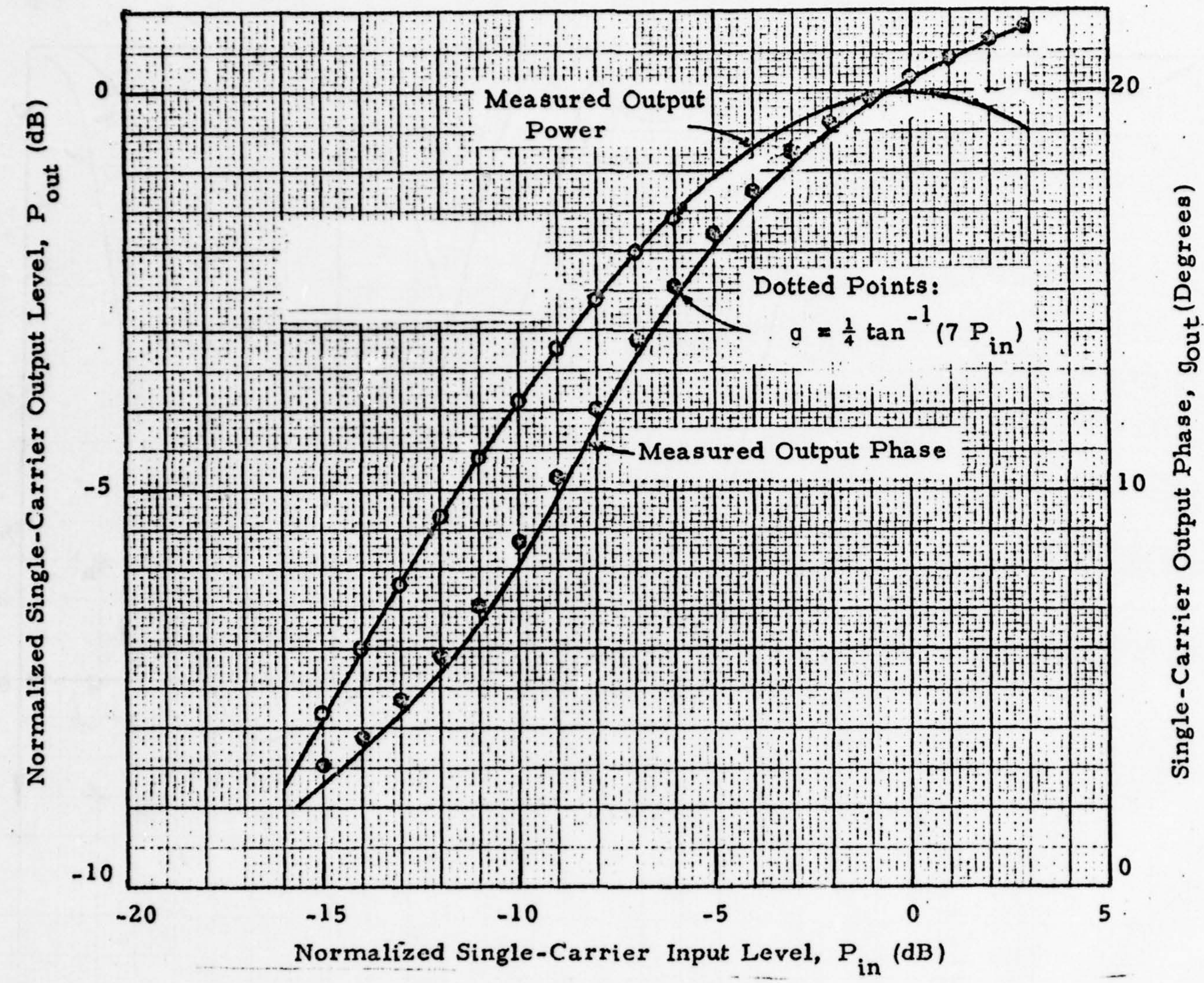


Figure 8. Measured TWT Characteristics

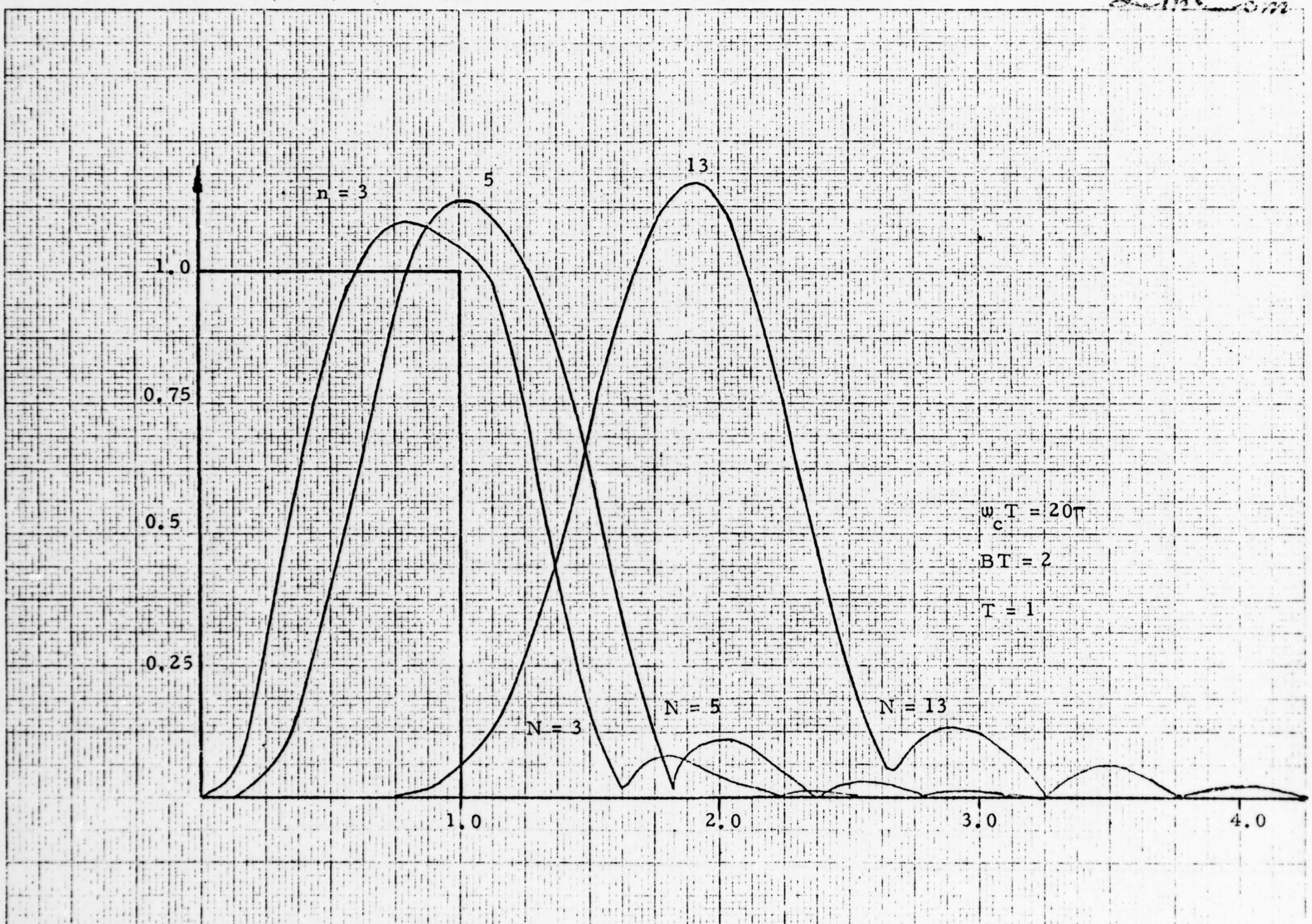


Figure 9. Envelope Response of Transmit IF Butterworth Filters

no intersymbol interference, we get typical uncoded symbol error rate curves shown in Figures 10 to 18 where the curves are parameterized by uplink signal-to-noise ratios. The dotted curves show the corresponding symbol error probability for the linear satellite repeater. Figures 10 to 12 are for the hard limiter satellite repeater for BPSK, QPSK, and 8PSK. The remaining six figures are for the soft limiter and TWT characteristics of Figures 7 and 8. Here β is the output power backoff and the downlink signal-to-noise ratio is defined by the maximum TWT power level. The computer programs that evaluate these error probabilities use the Gauss-quadrature formulas.

The effects of intersymbol interference parameterized by BT are shown in Figures 19 to 21. Here we assume the demodulator is memoryless and does not take advantage of the memory in the intersymbol interference.

Coding Analysis

The coding analysis is based on the computational cutoff rate which was suggested recently by Massey (Reference 7) as an effective way of comparing various communication systems from a coding point of view. Here we first computed the computational cutoff rates for the hard decision channels created by the system of Figure 6. For BPSK the hard decision computational cutoff rate, $r(2)$, can be expressed directly in terms of the uncoded symbol error probability and this is given in Figure 22. For the same set of system parameters of

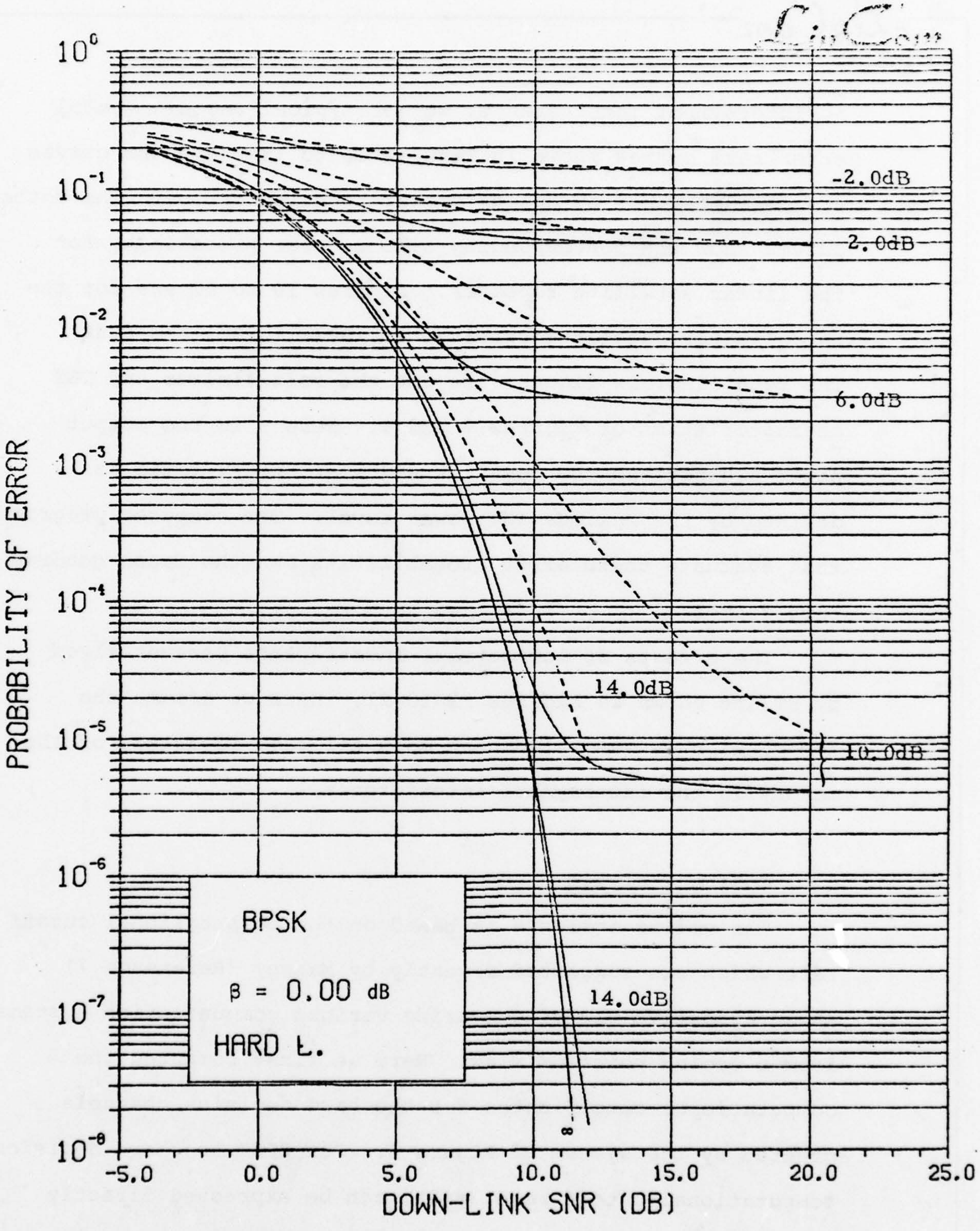


Figure 10. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

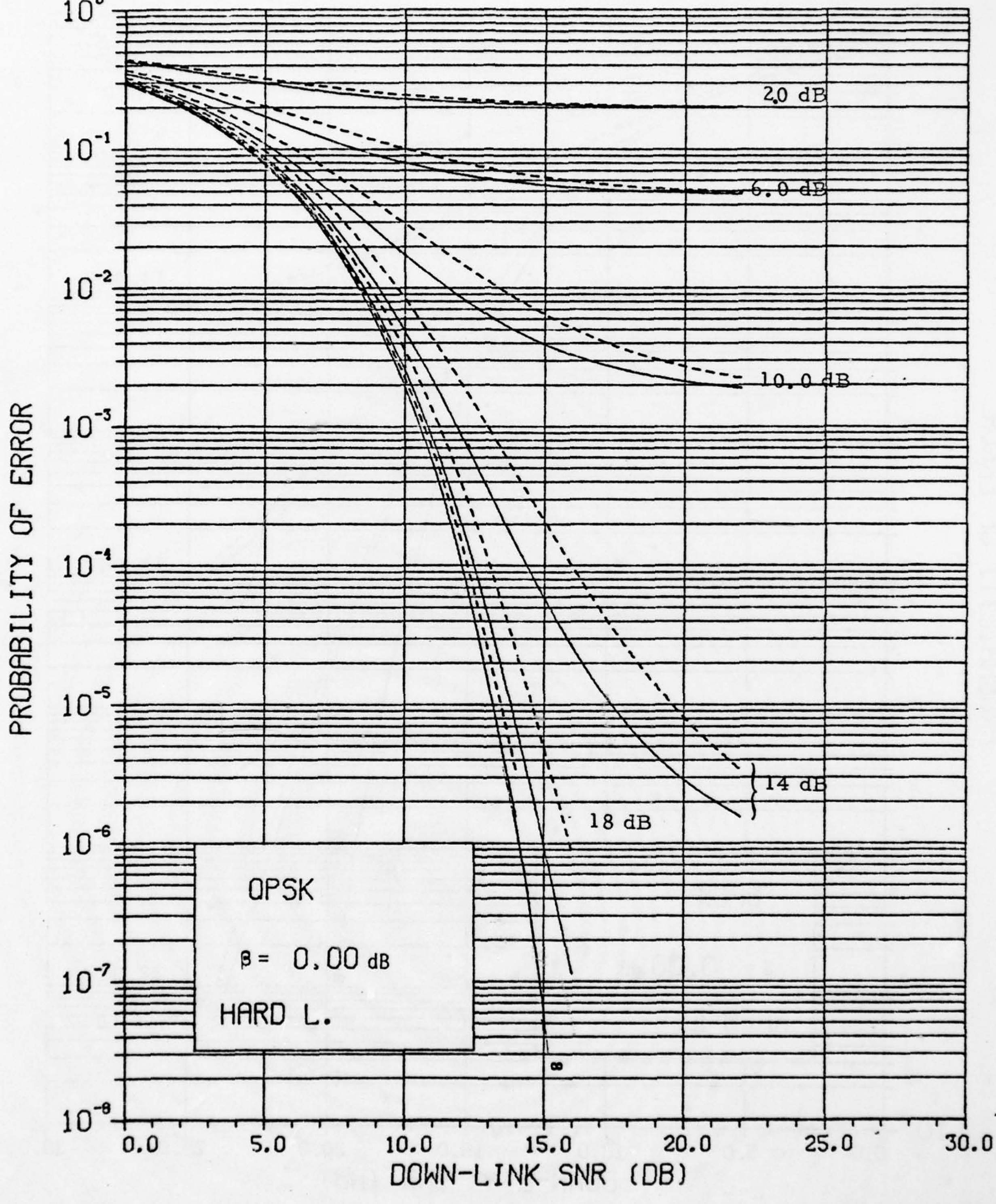


Figure 11. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

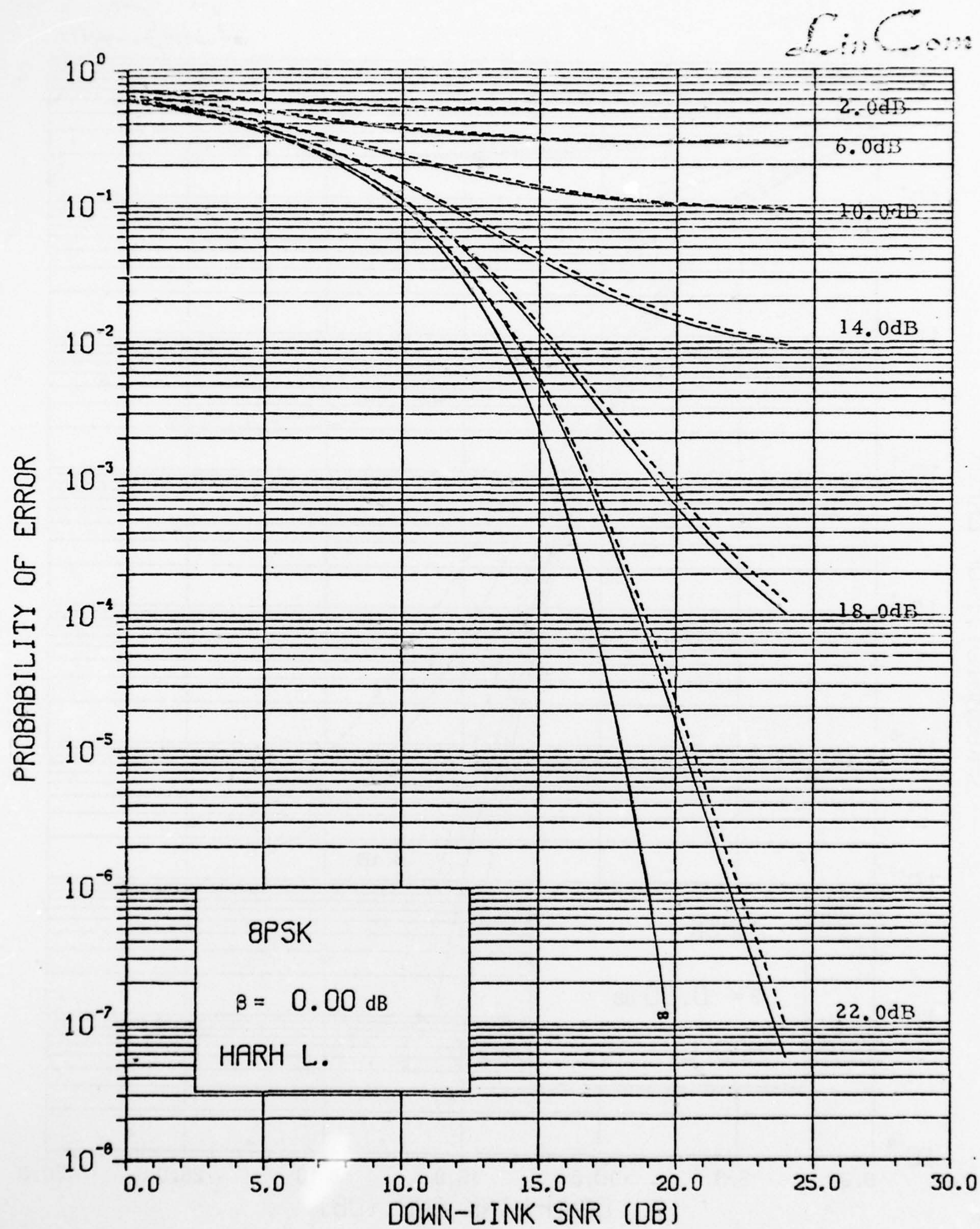


Figure 12. Symbol Error Probability vs. Downlink SNR With Uplink SNR as a Parameter

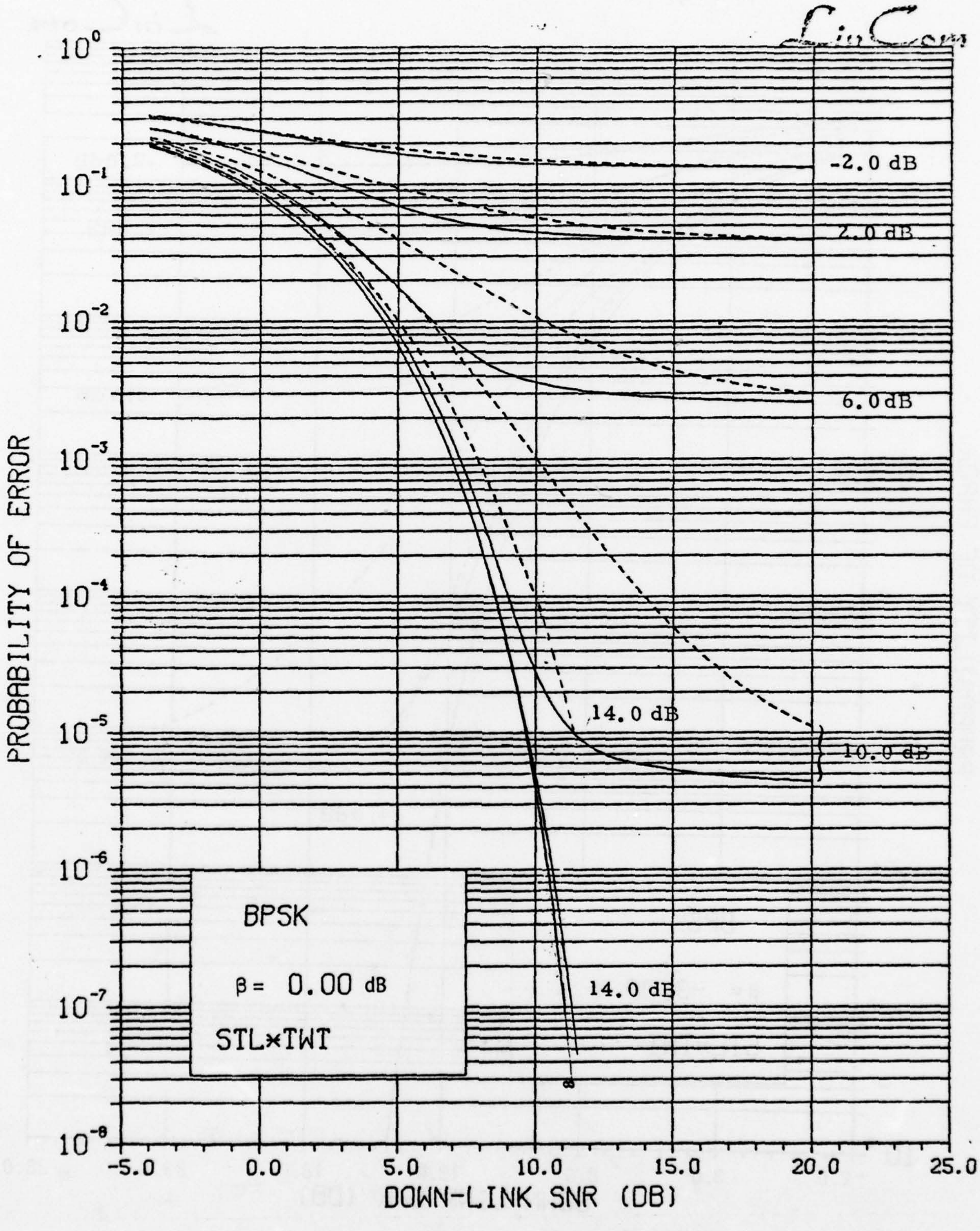


Figure 13. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

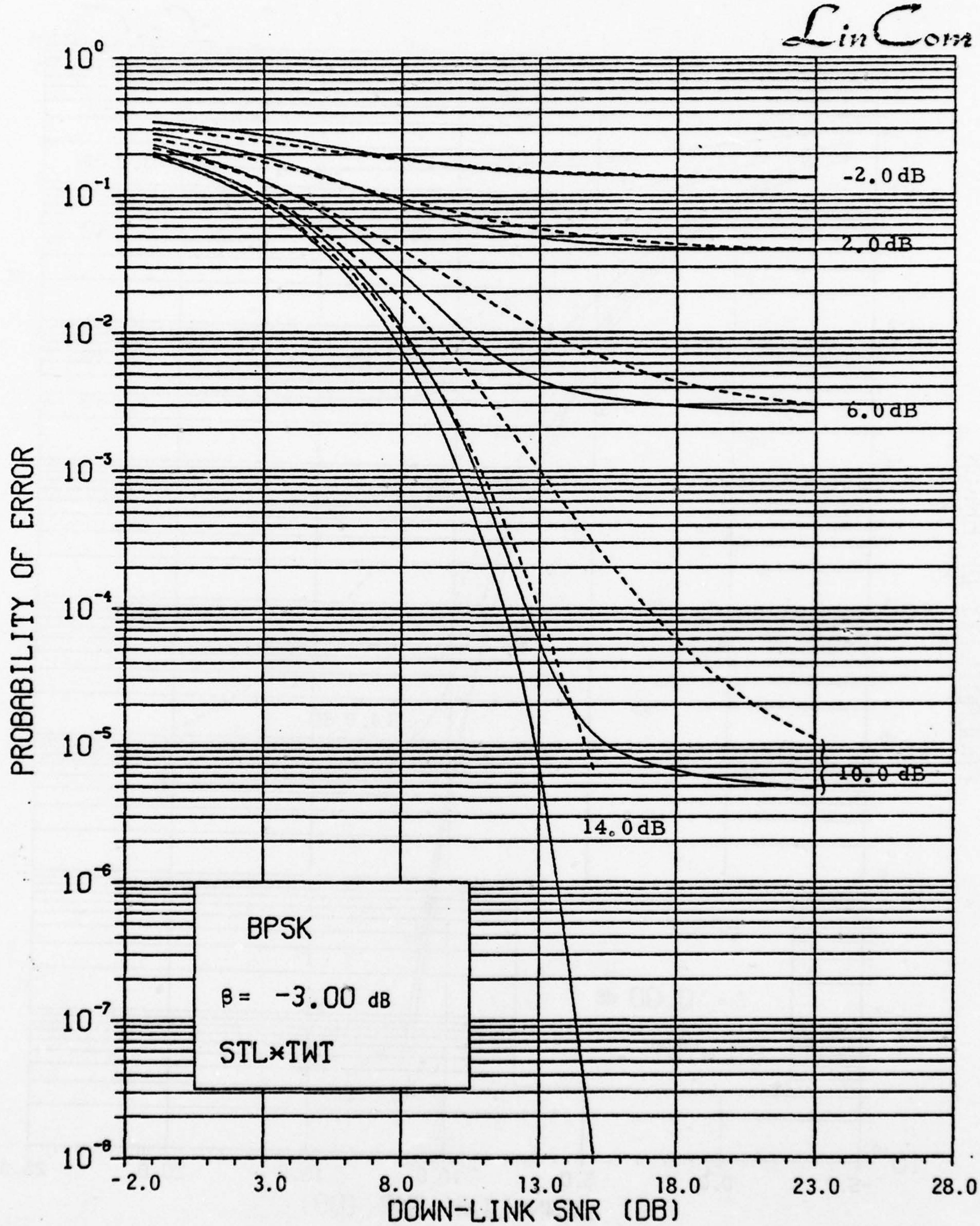


Figure 14. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

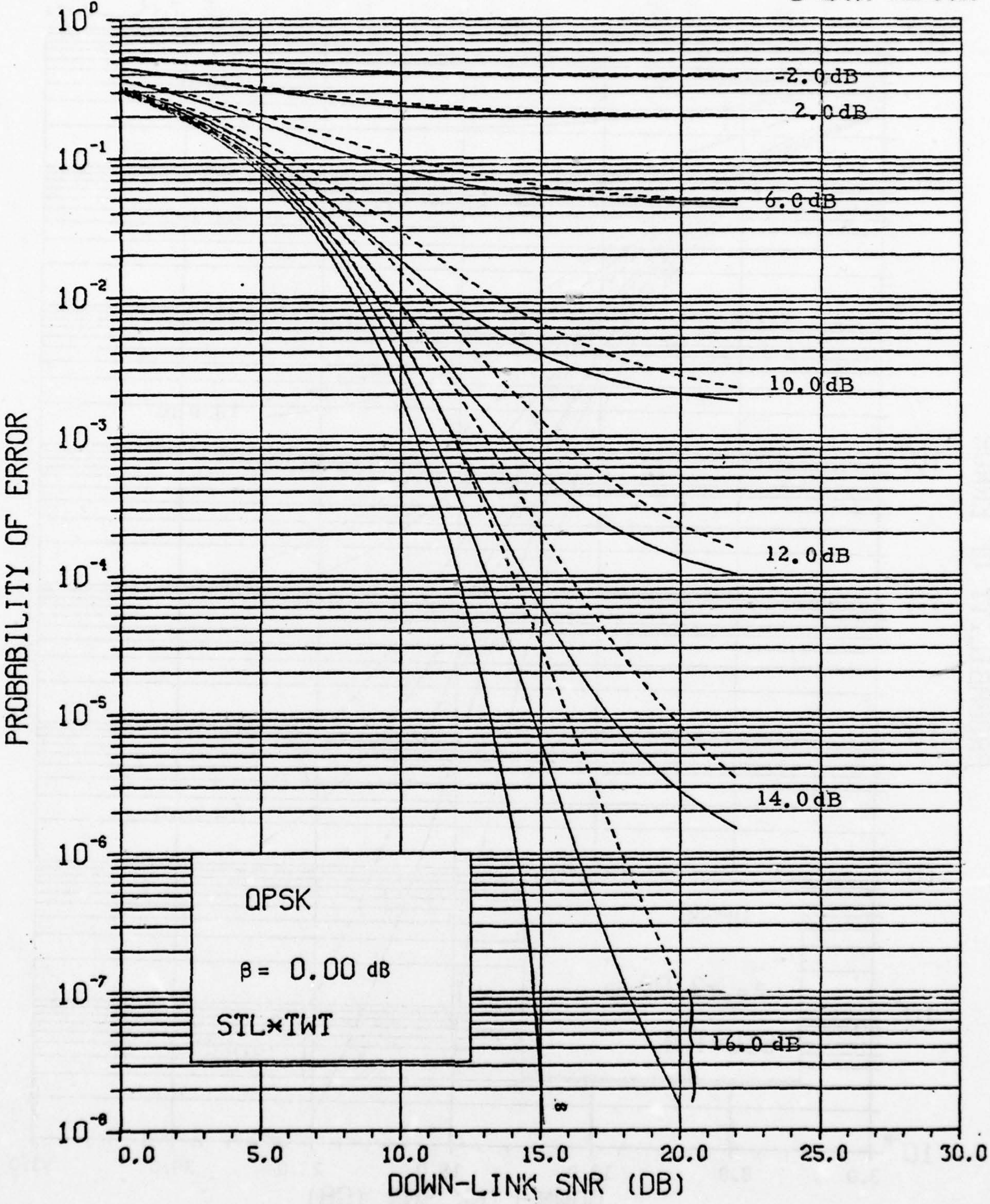


Figure 15. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

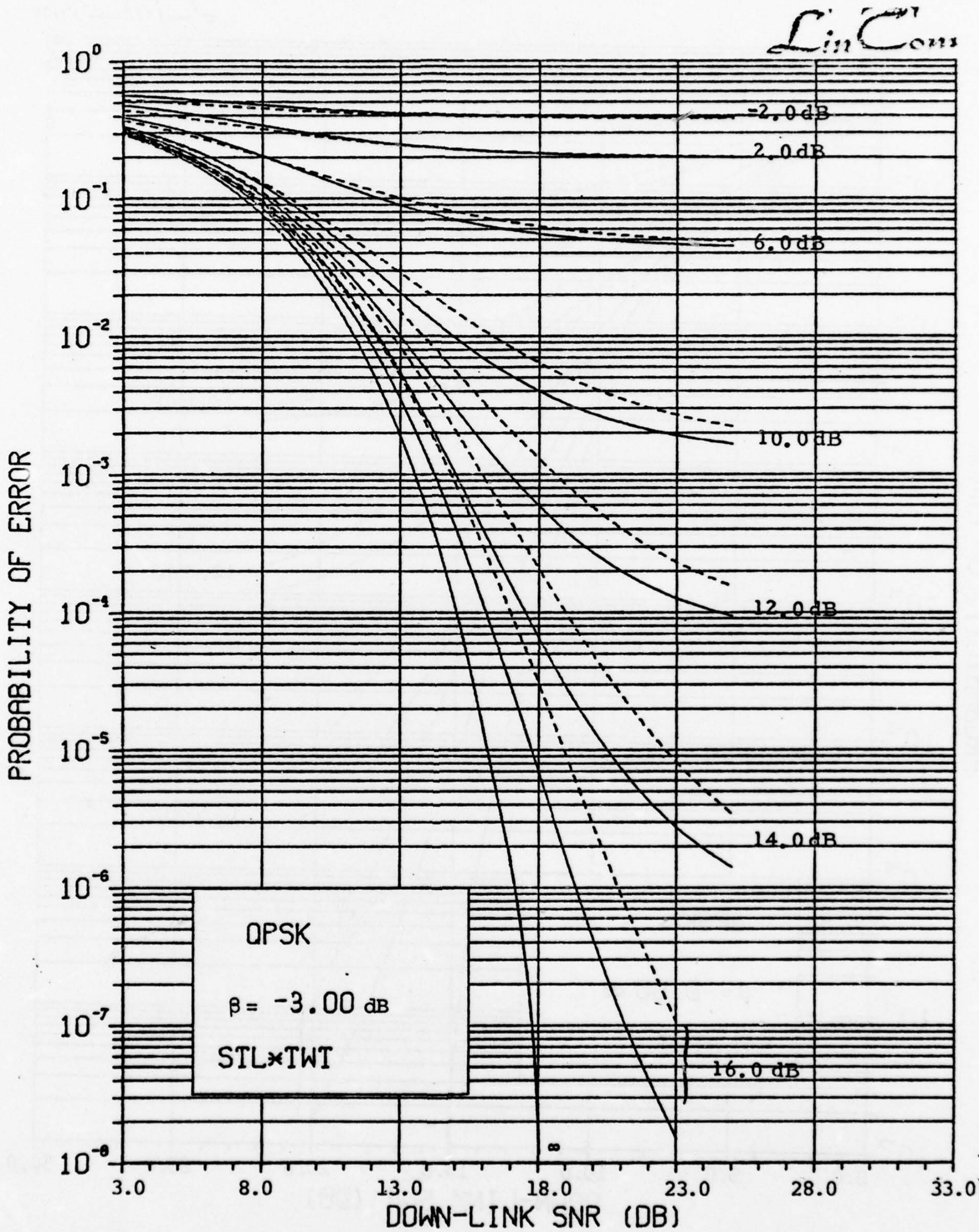


Figure 16. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

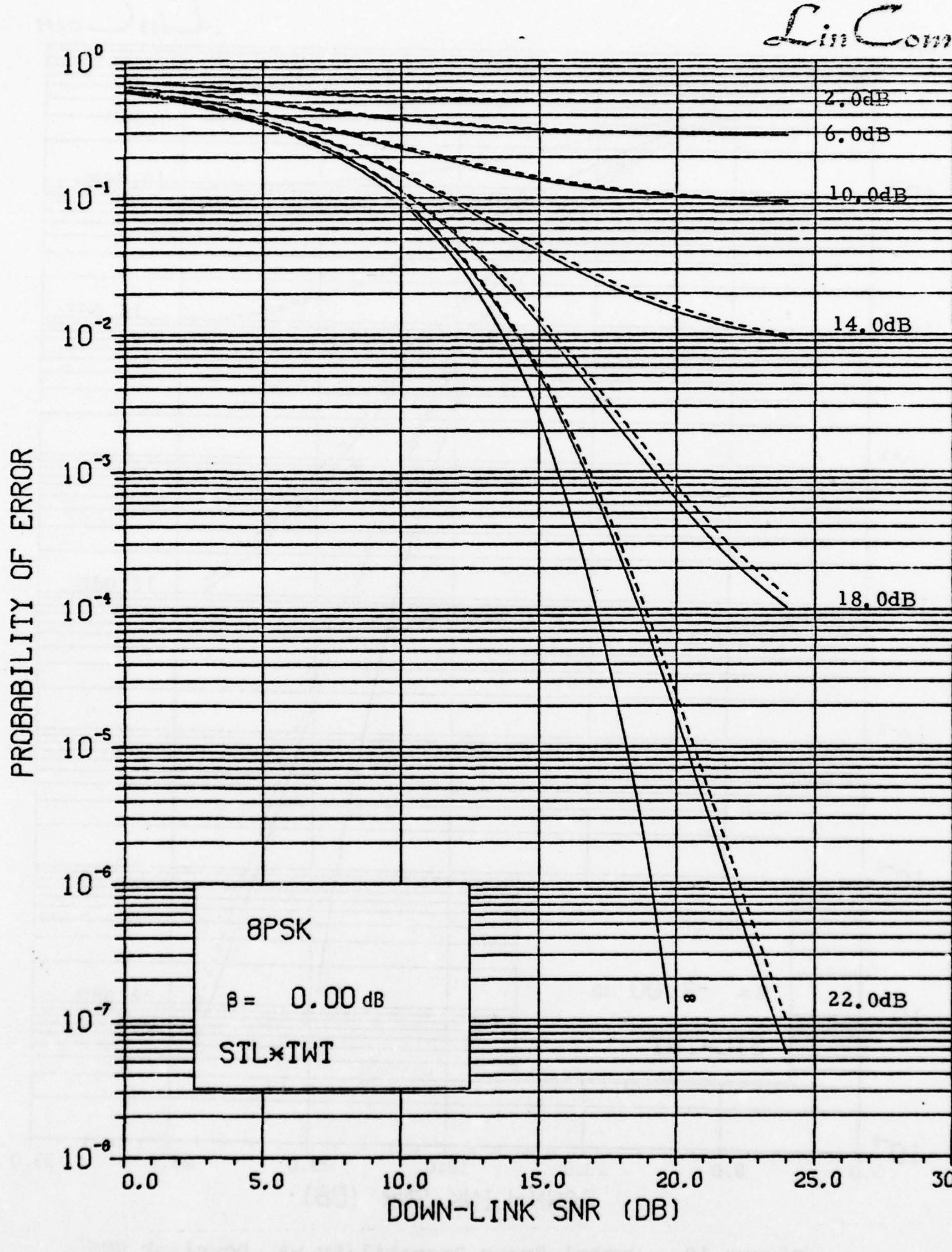


Figure 17. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

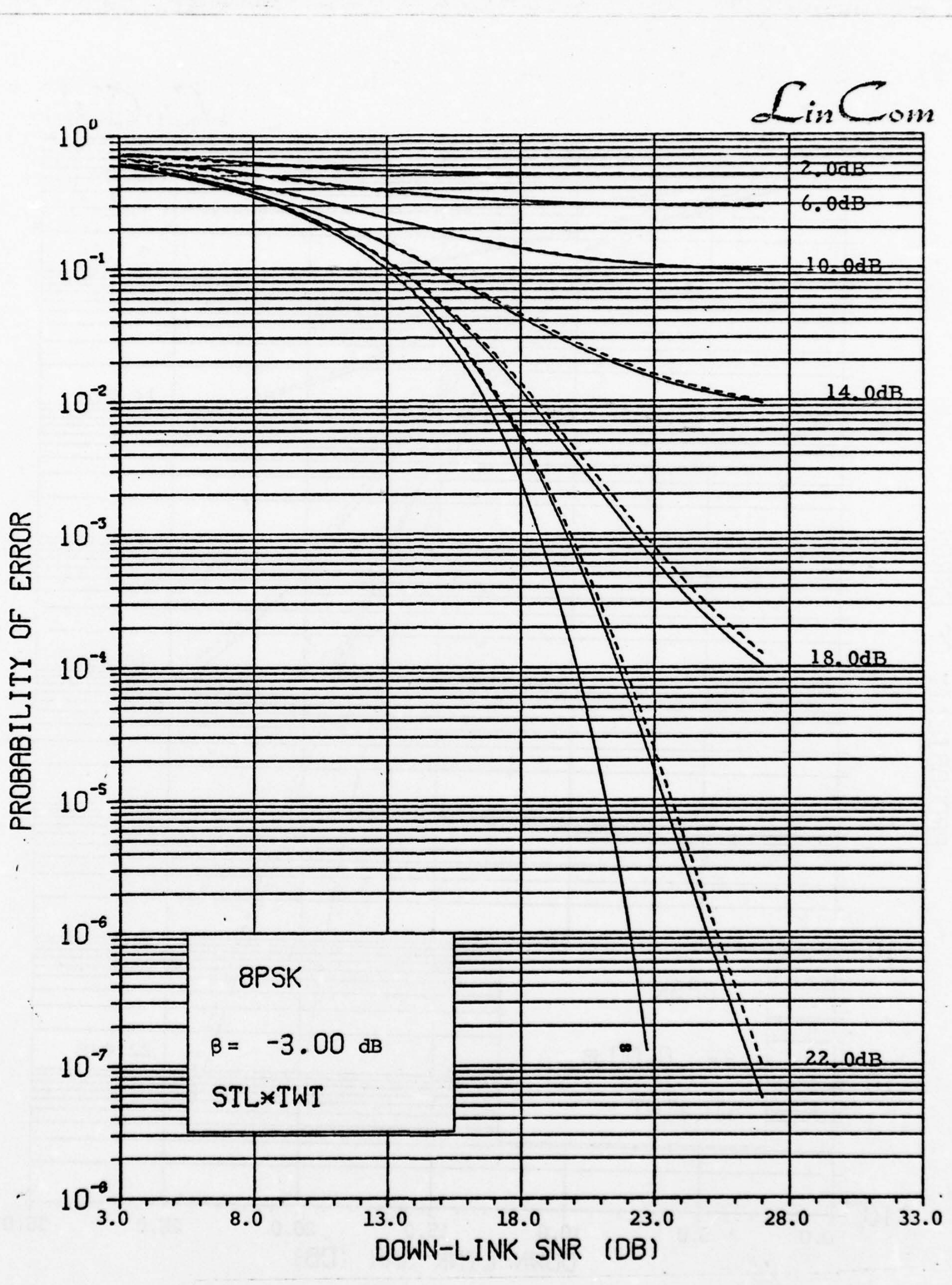


Figure 18. Symbol Error Probability vs. Downlink SNR with Uplink SNR as a Parameter

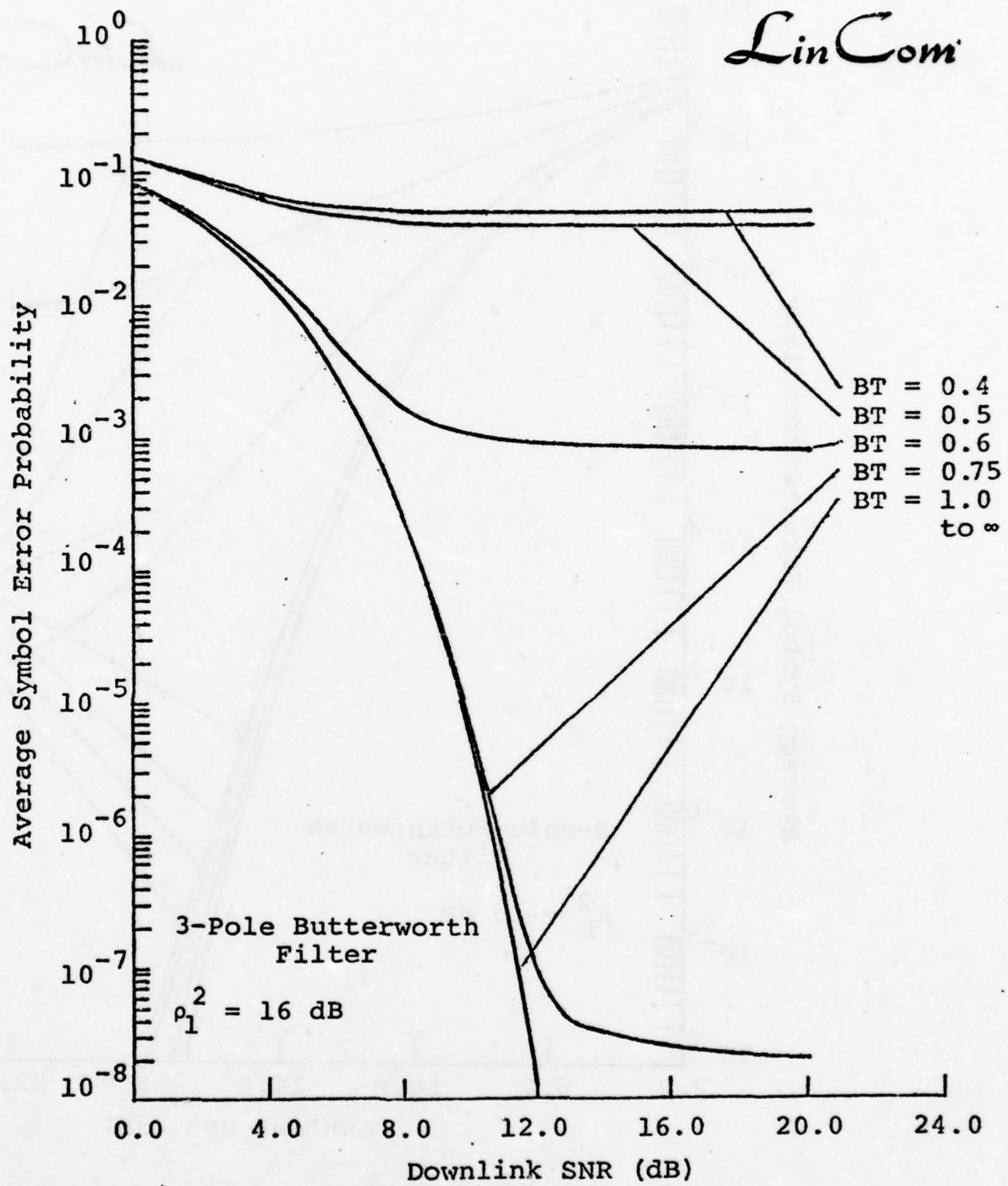


Figure 19. BPSK Average Symbol Error Probability vs. Downlink SNR: Memoryless Demodulator

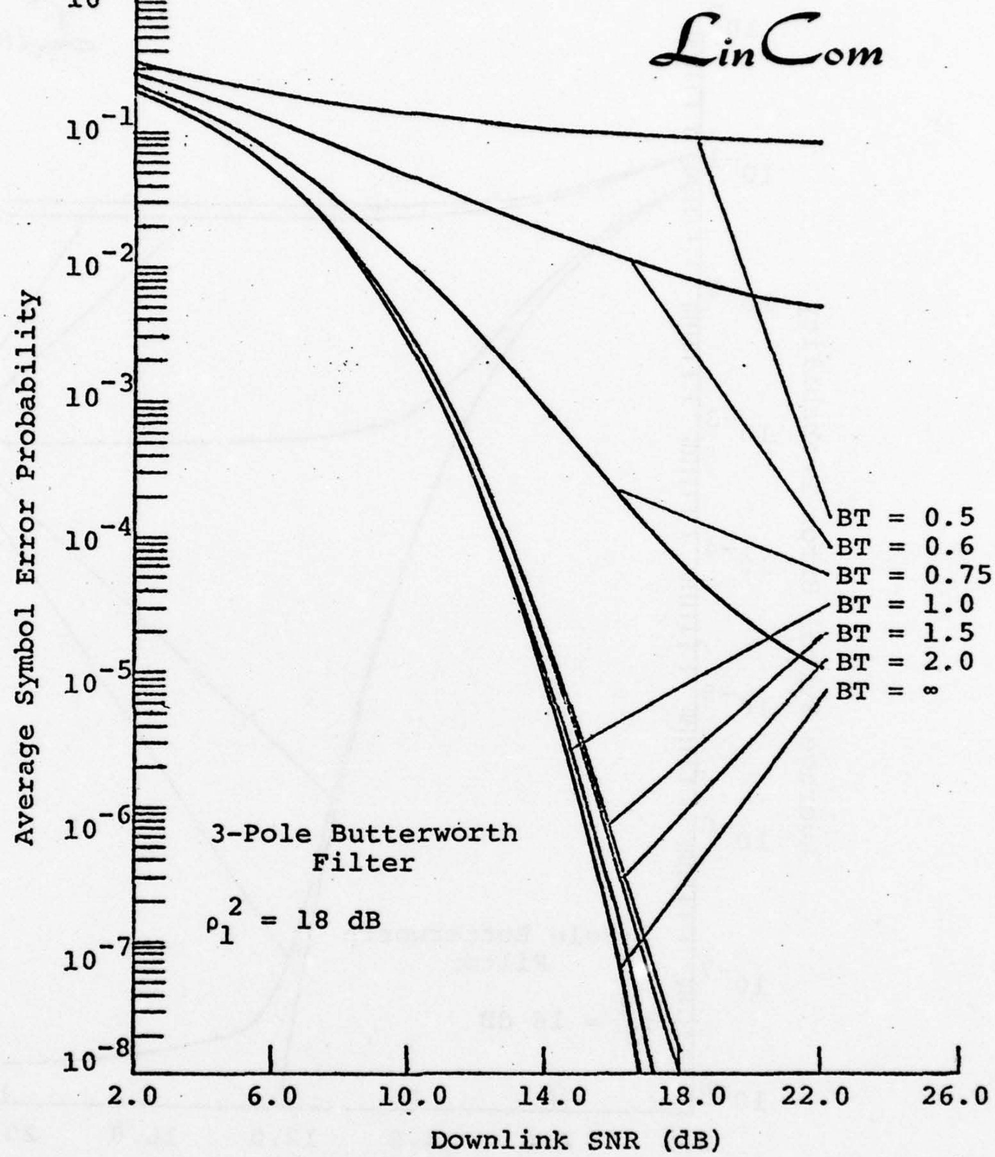


Figure 20. QPSK Average Symbol Error Probability vs. Downlink SNR: Memoryless Demodulator

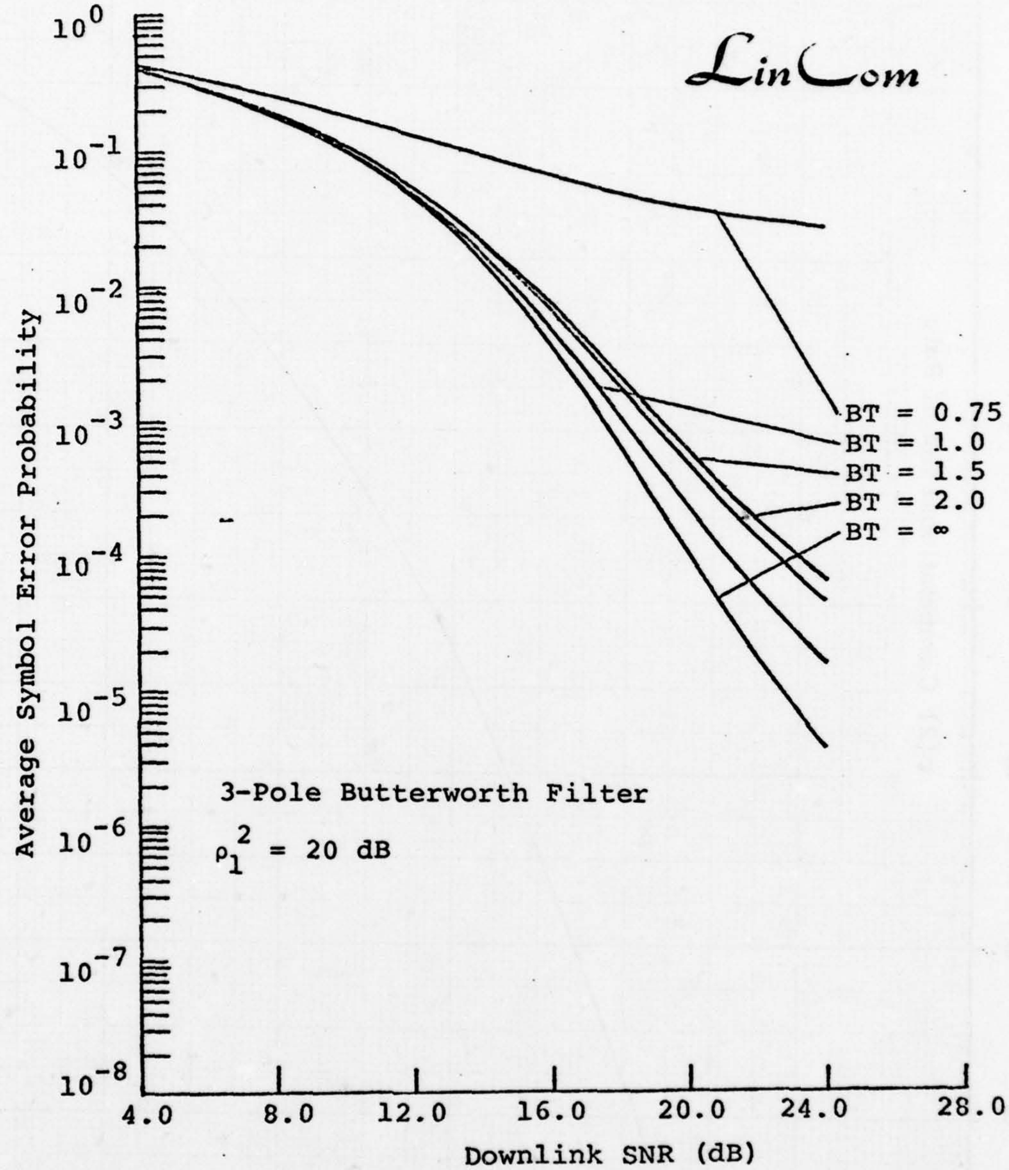


Figure 21. 8PSK Average Symbol Error Probability vs. Downlink SNR: Memoryless Demodulator

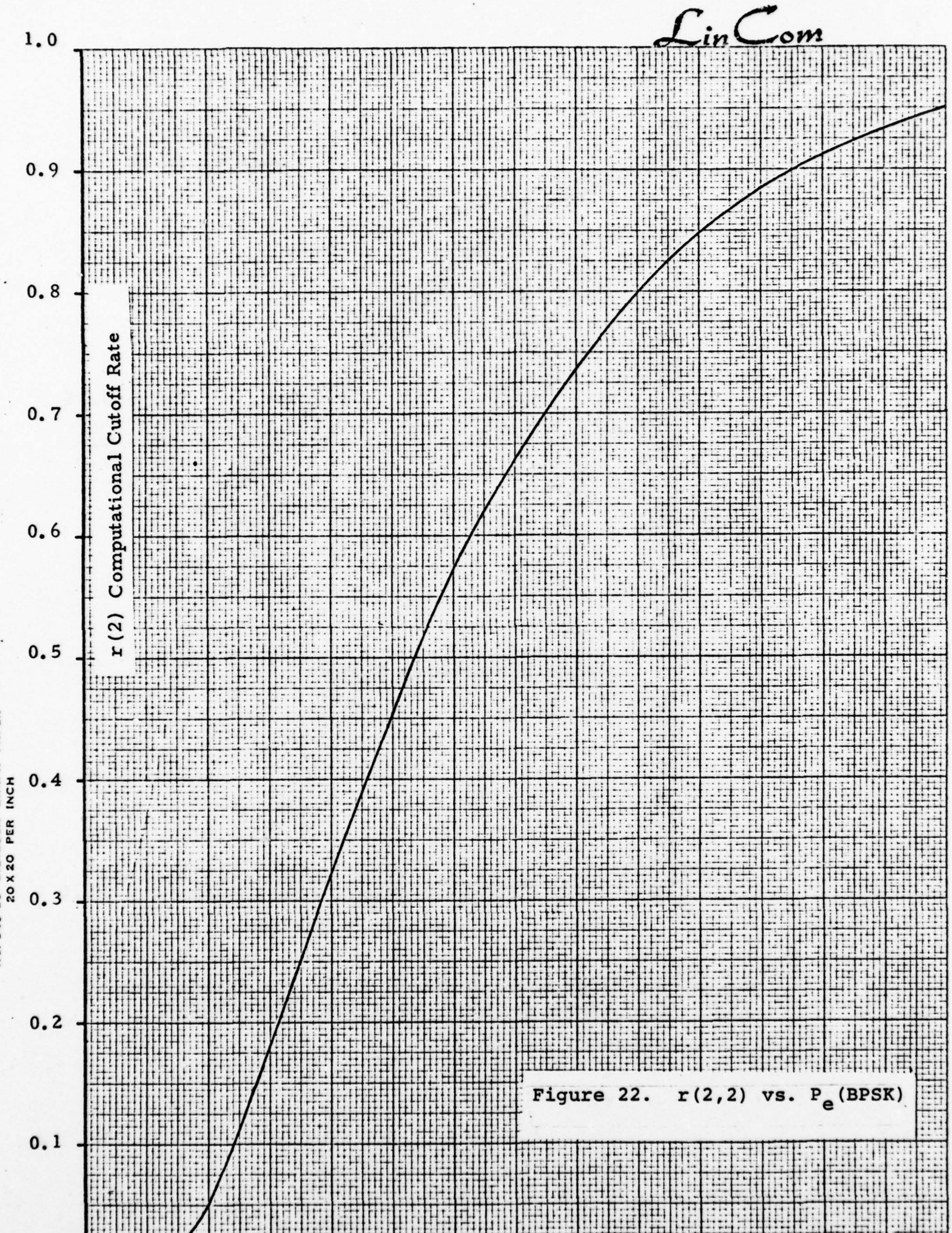


Figure 22. r(2,2) vs. P_e(BPSK)

the uncoded symbol error probabilities of Figures 10 to 18, we have the hard decision computational cutoff rates shown in Figures 23 to 31.

The evaluation of the computational cutoff rates allow us to examine the tradeoffs between data rates, decoding complexity, and coded data bit error probabilities. Define R_o as the computational cutoff rate of the communication system of Figure 6 measured in bits per second. Let R be the actual data rate in bits per second. Then using a random coding union bound on the coded data bit error probability we arrive at Figures 32 and 33 which show coded data bit error probability versus the ratio R_o/R for various values of K, the memory of the encoding device. Generally the complexity of the coding system grows exponentially with K. Hence given a limit on coding complexity which fixes K, for a given required coded bit error probability we can obtain the ratio R_o/R. Then it is clear that the communication channel with the largest value of the computational cutoff rate will allow the largest data rate under these conditions.

Figures 32 and 33 are based on random coding bounds and show achievable performance without specifying particular codes. Oldenwalder (Reference 10) found optimal binary convolutional codes for which one would expect better performance than the random coding bounds. Heller and Jacobs (Reference 11) computed the performance of these optimum codes which we show in Figure 34 for the special case of rate $\frac{1}{2}$ bit per channel bit convolutional codes and hard decision

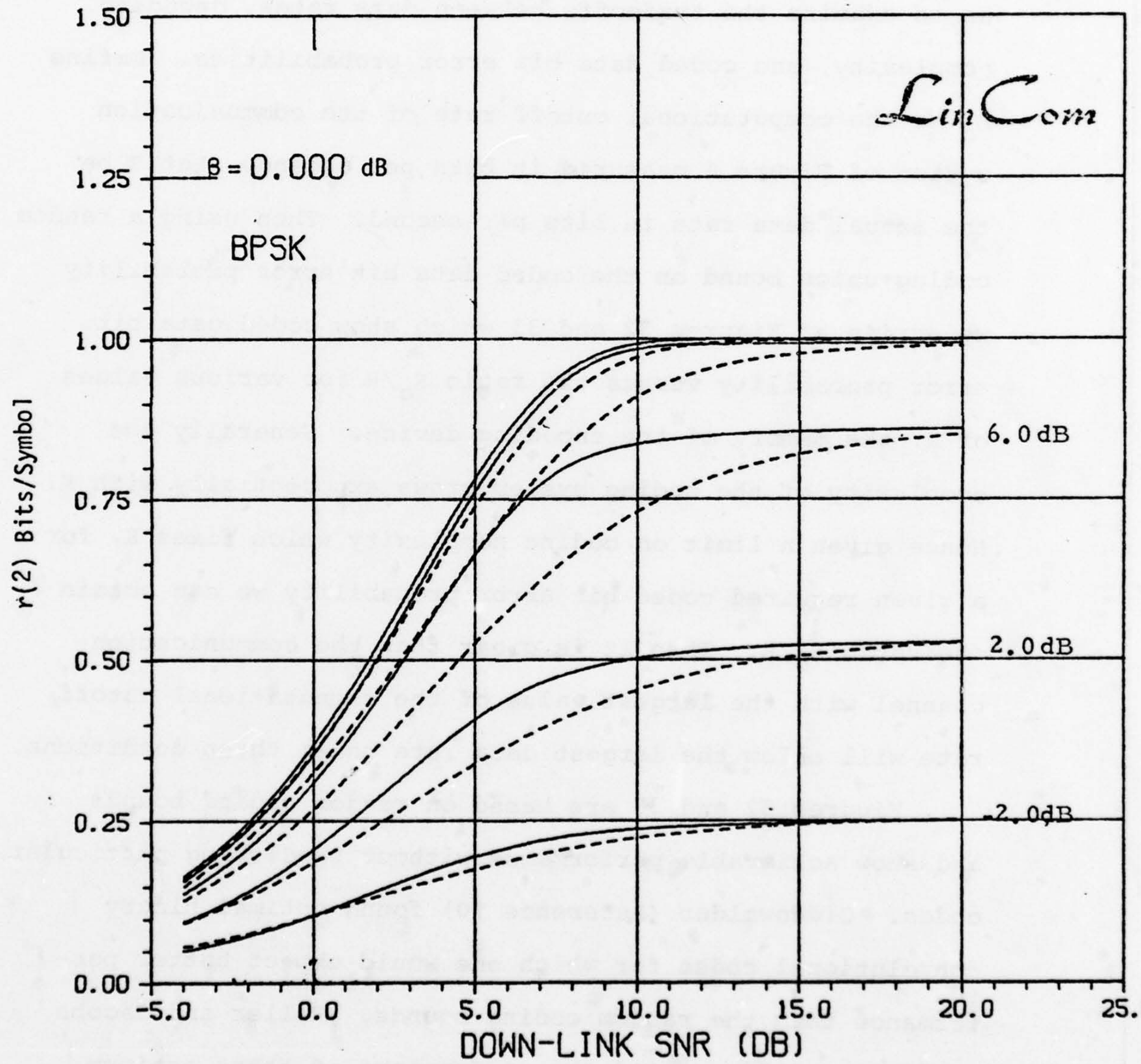


Figure 23. Computational Cutoff Rate versus Downlink SNR - Hard Limiter

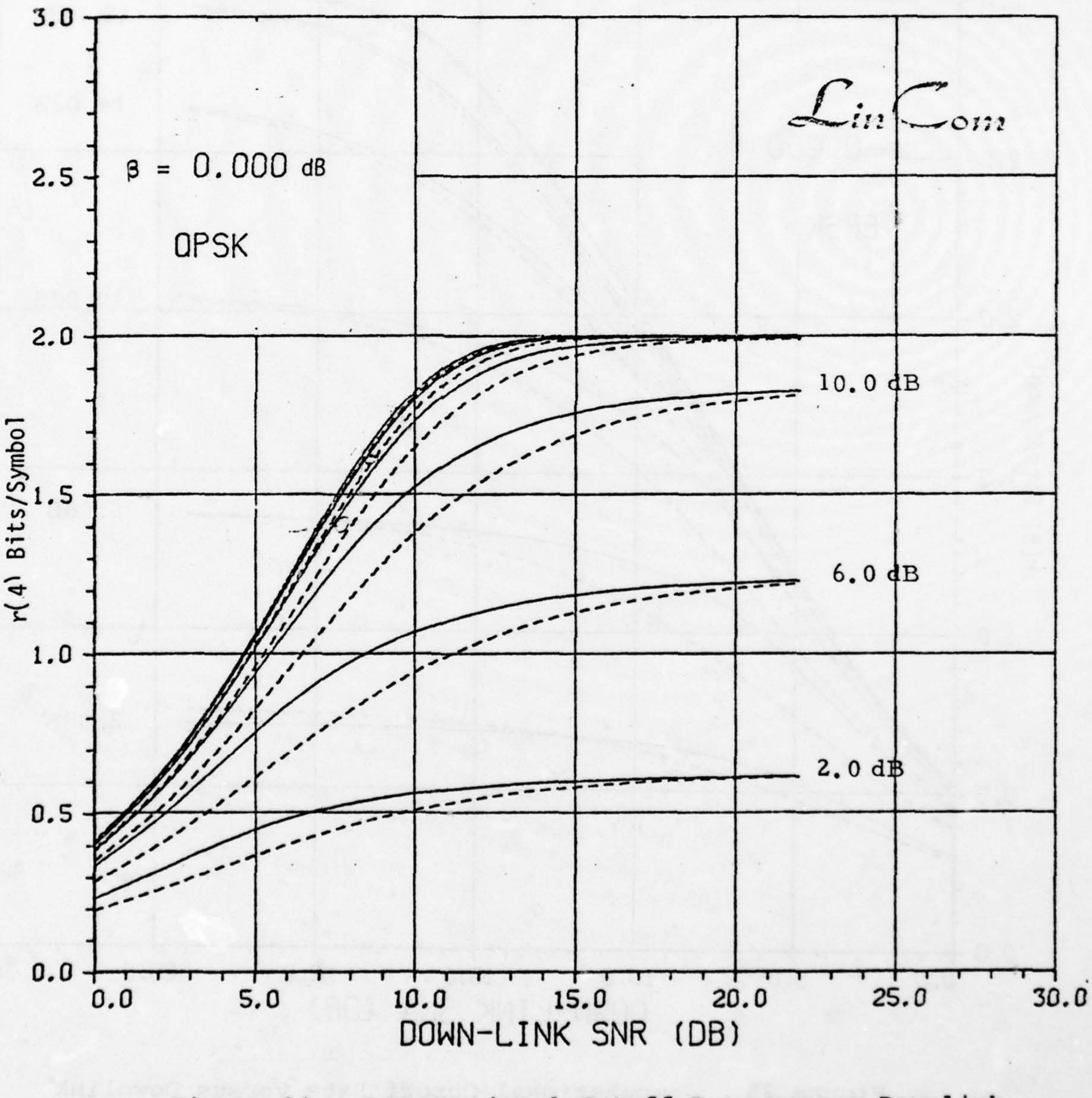


Figure 24. Computational Cutoff Rate versus Downlink SNR - Hard Limiter

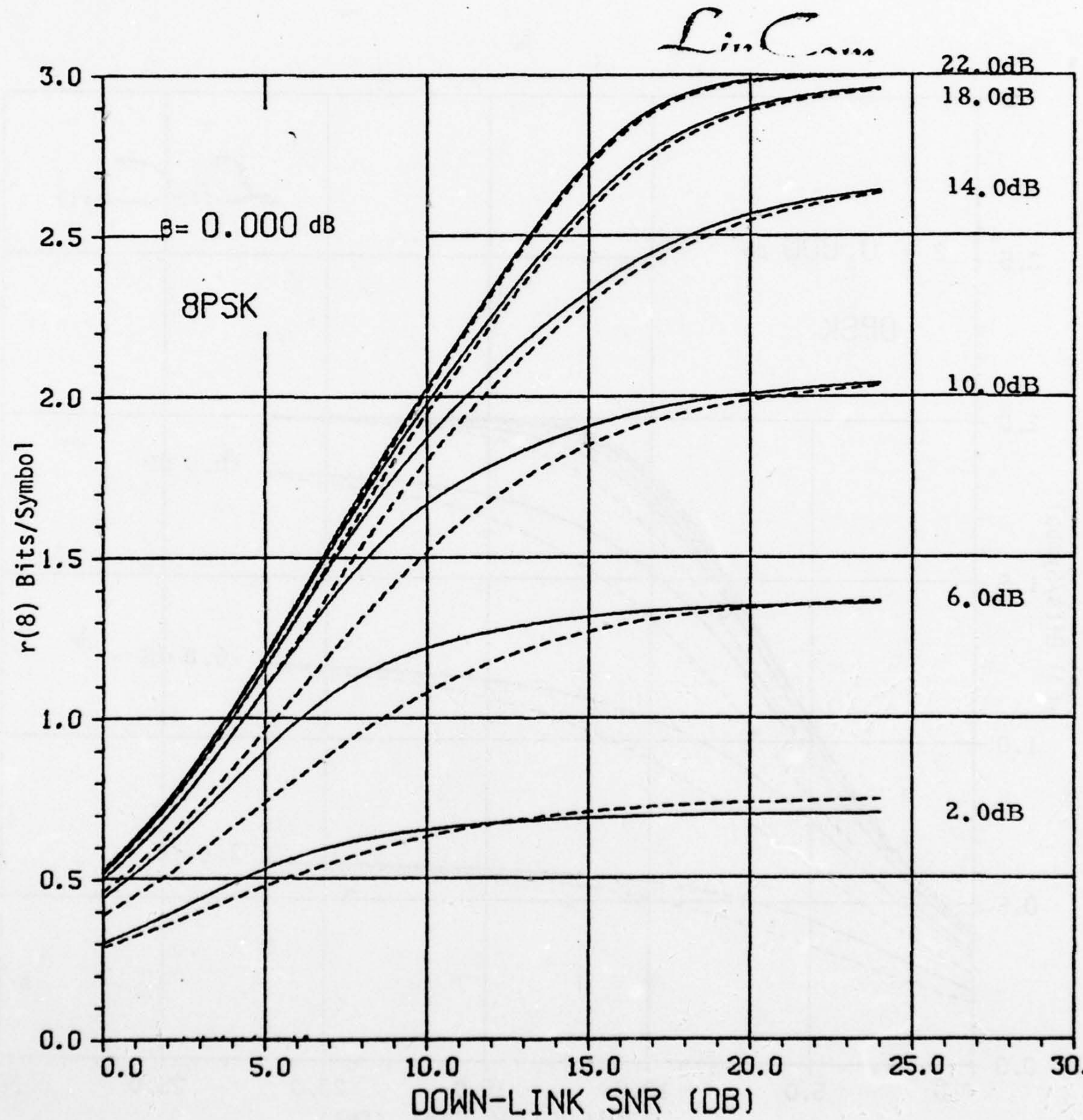


Figure 25. Computational Cutoff Rate versus Downlink SNR - Hard Limiter

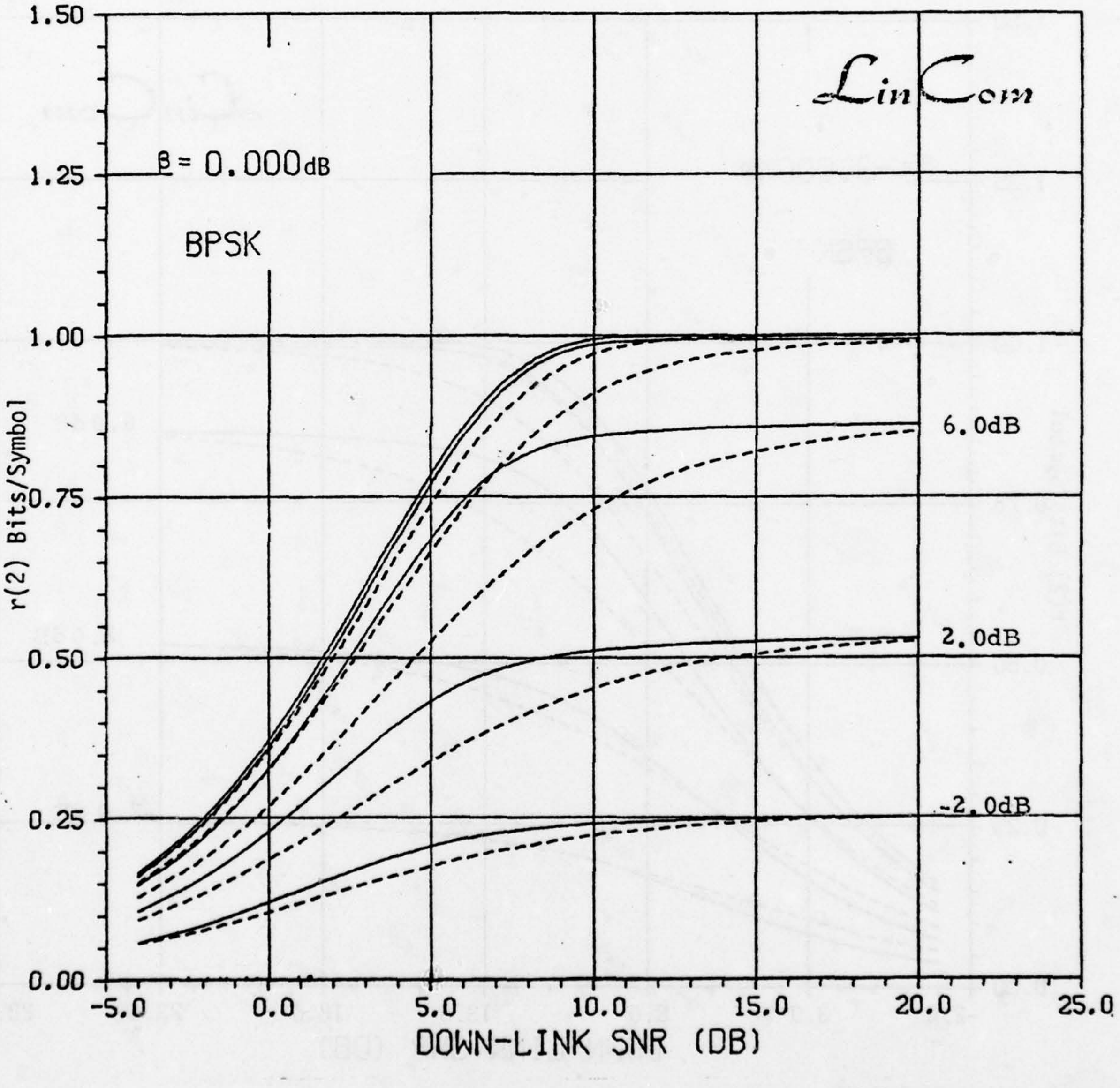


Figure 26. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

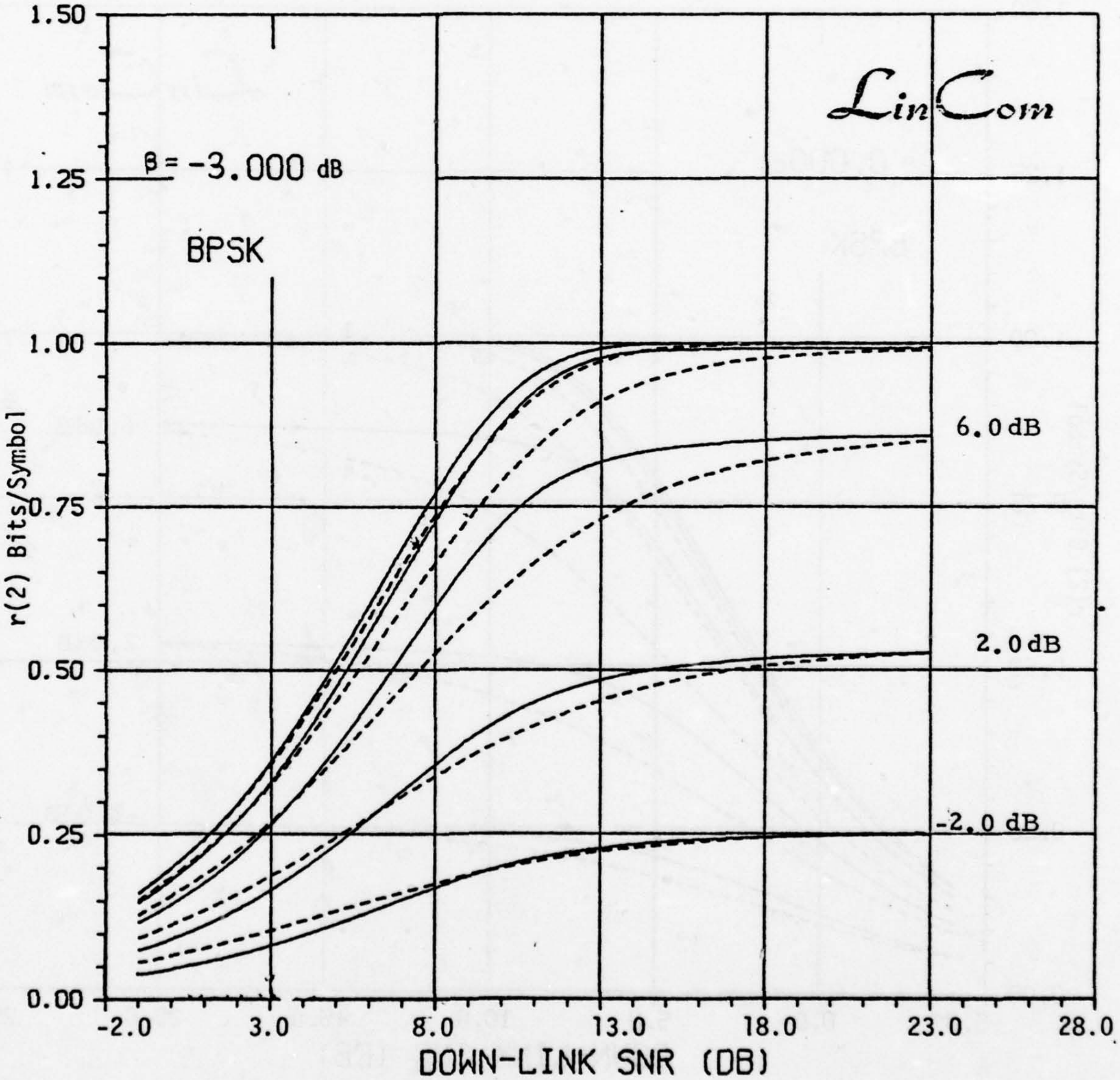


Figure 27. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

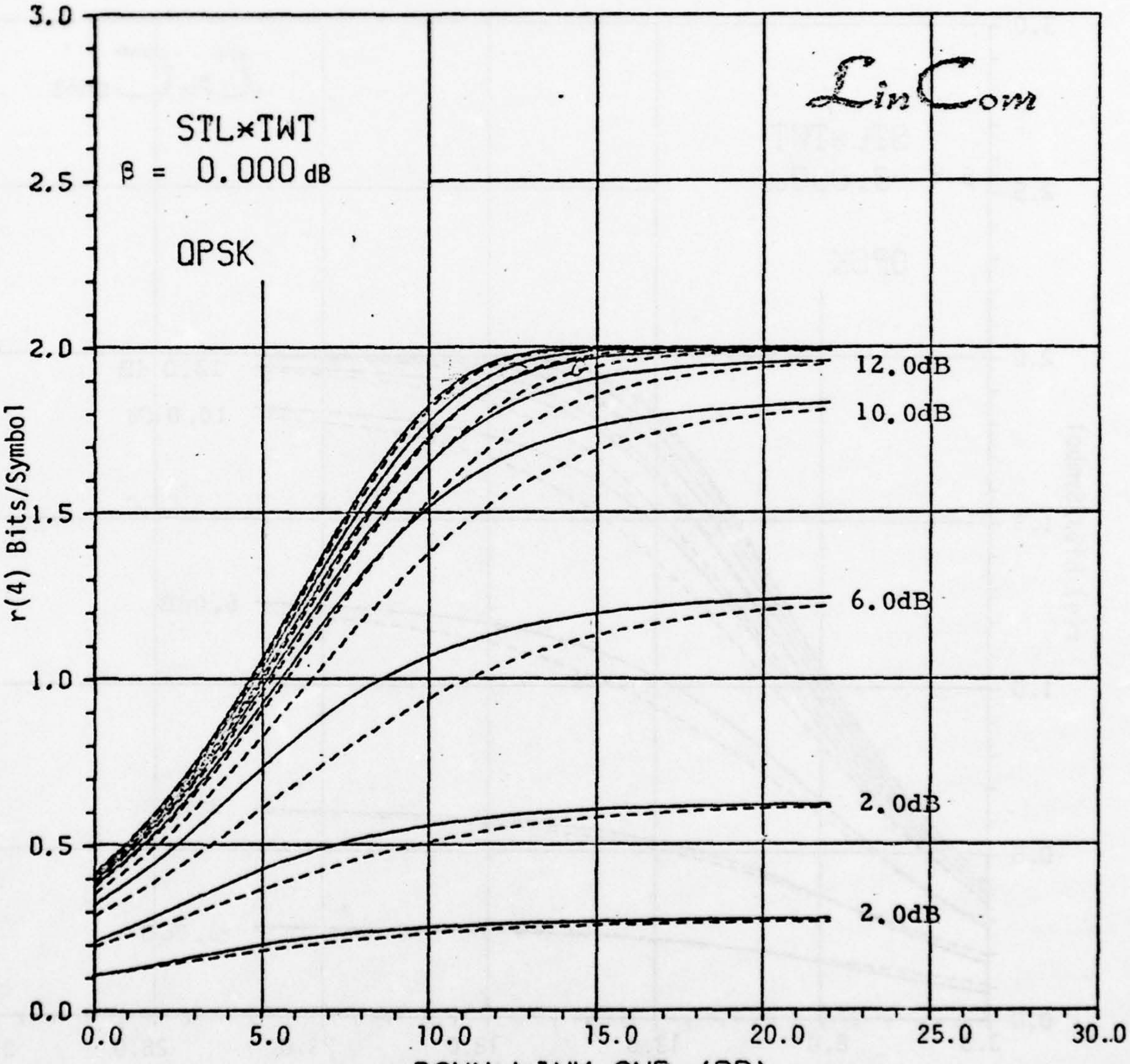


Figure 28. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

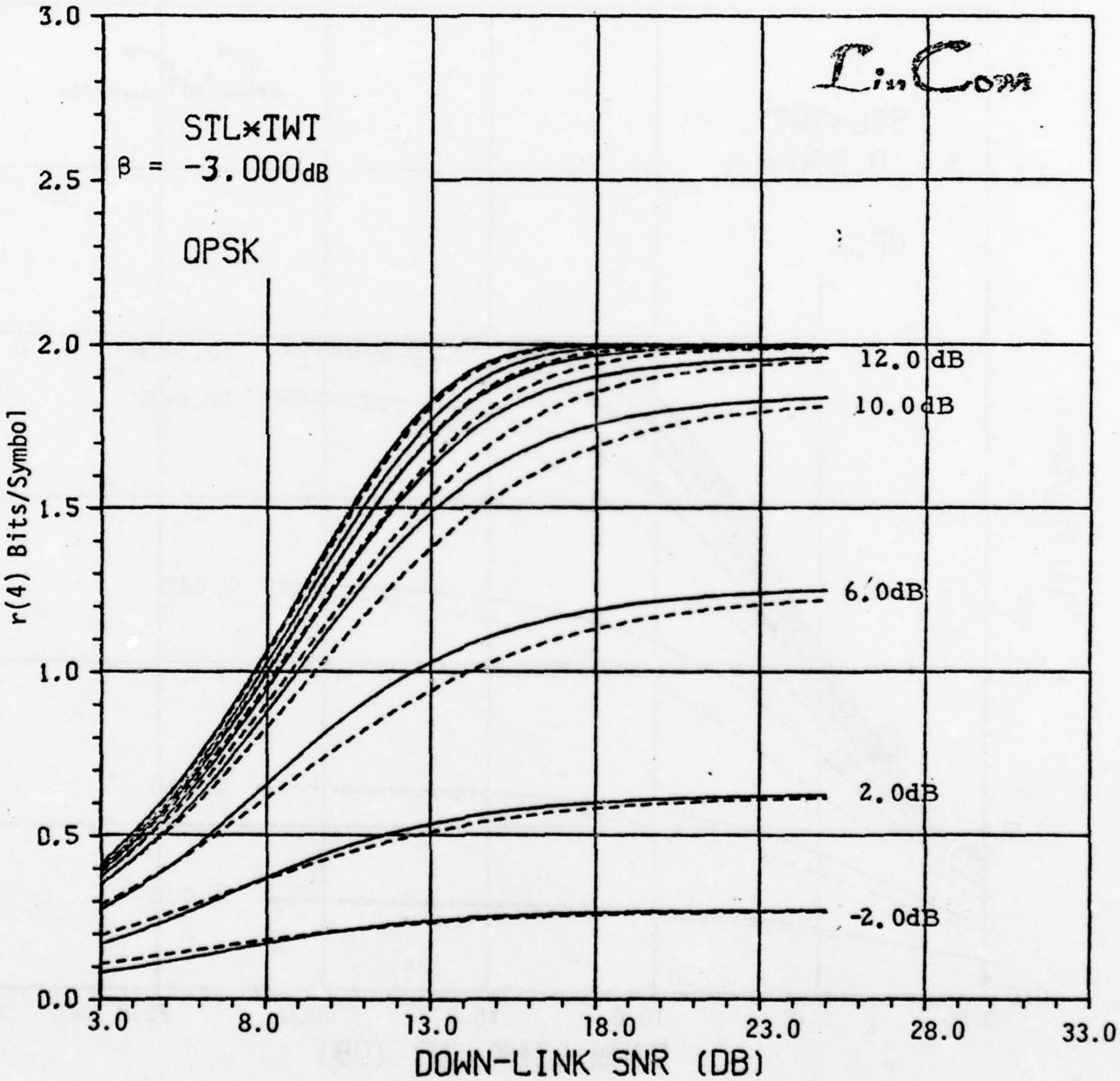


Figure 29. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

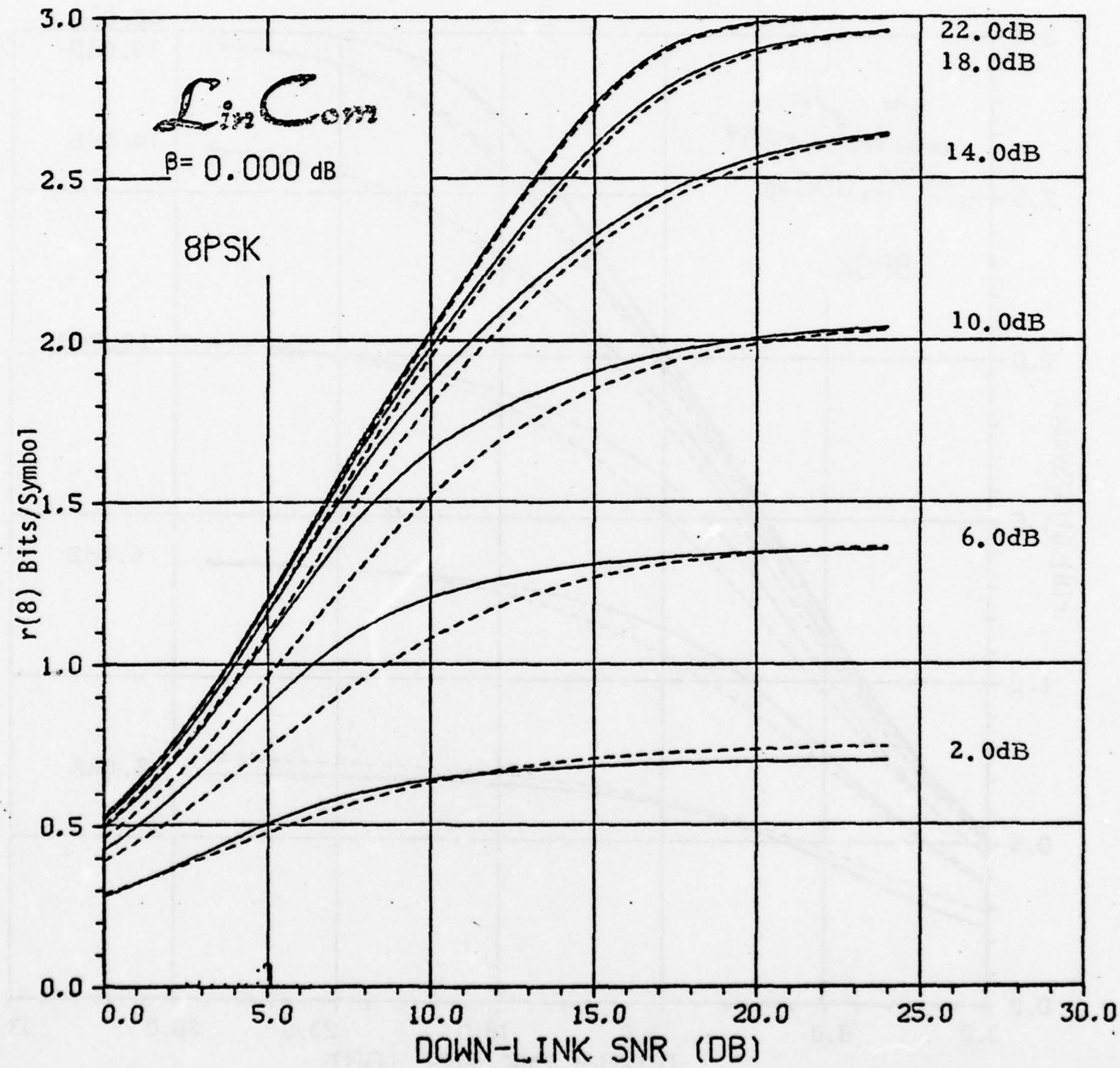


Figure 30. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

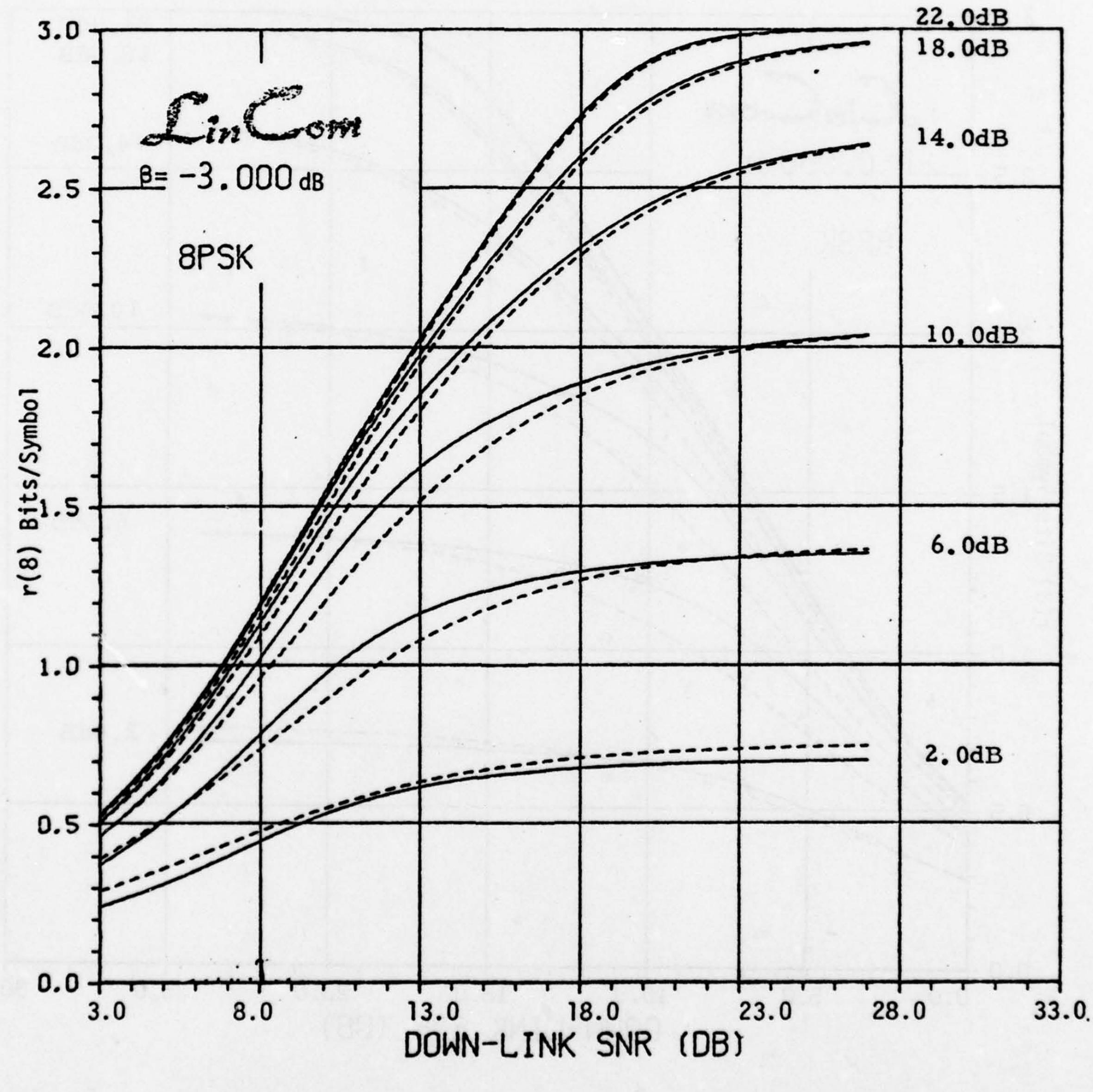


Figure 31. Computational Cutoff Rate versus Downlink SNR - Soft Limiter

Figure 32. Block Code Coding Bound

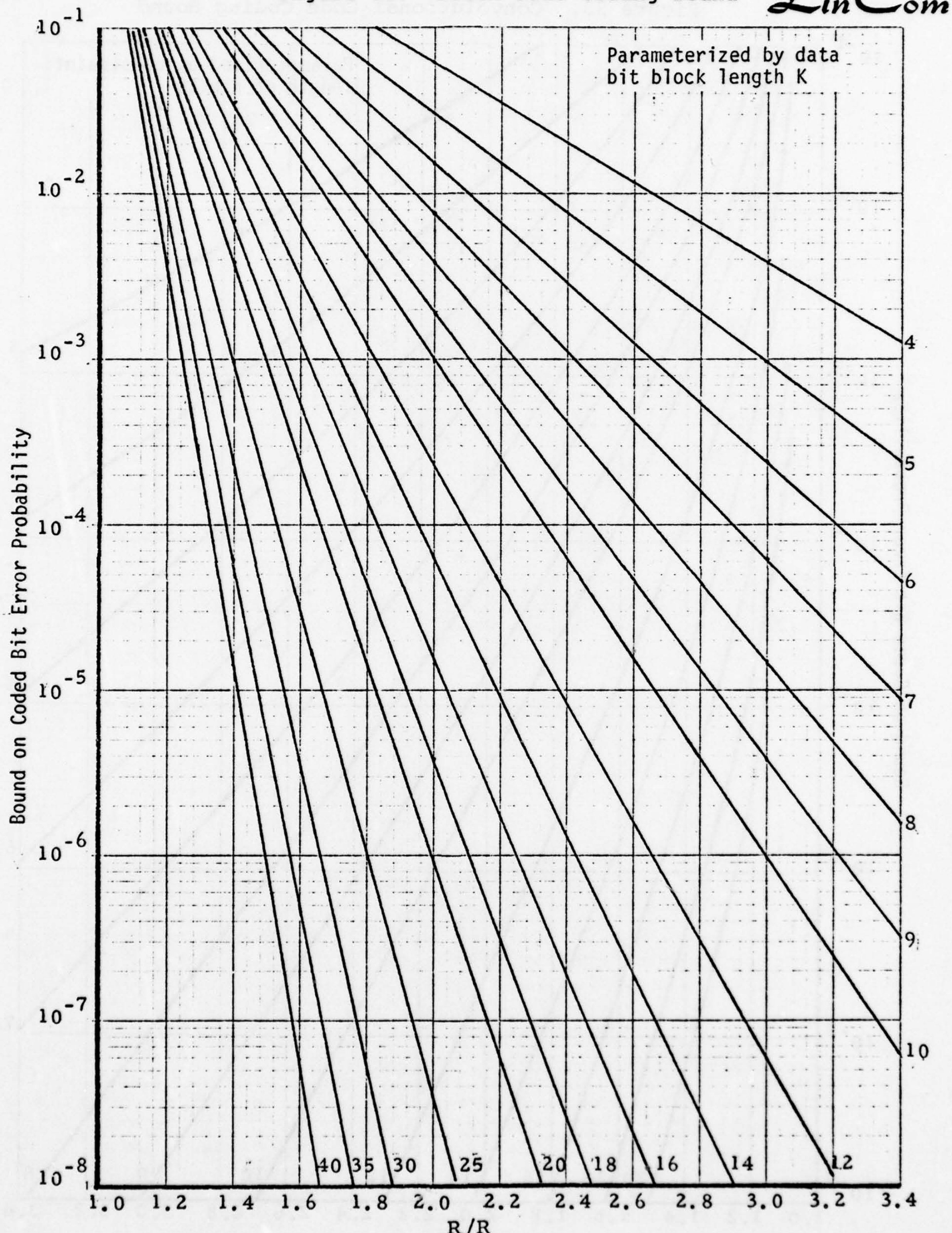
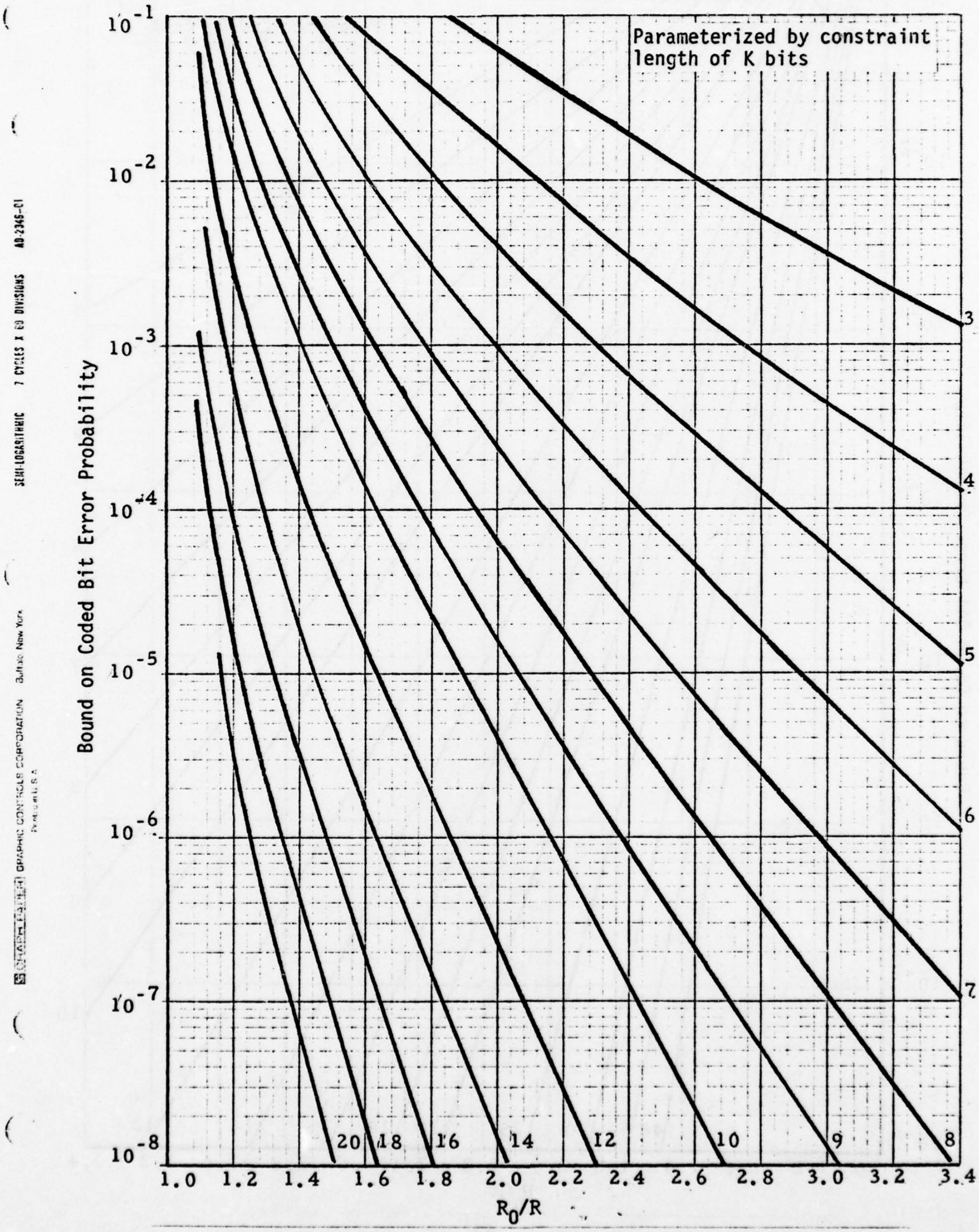


Figure 33. Convolutional Code Coding Bound



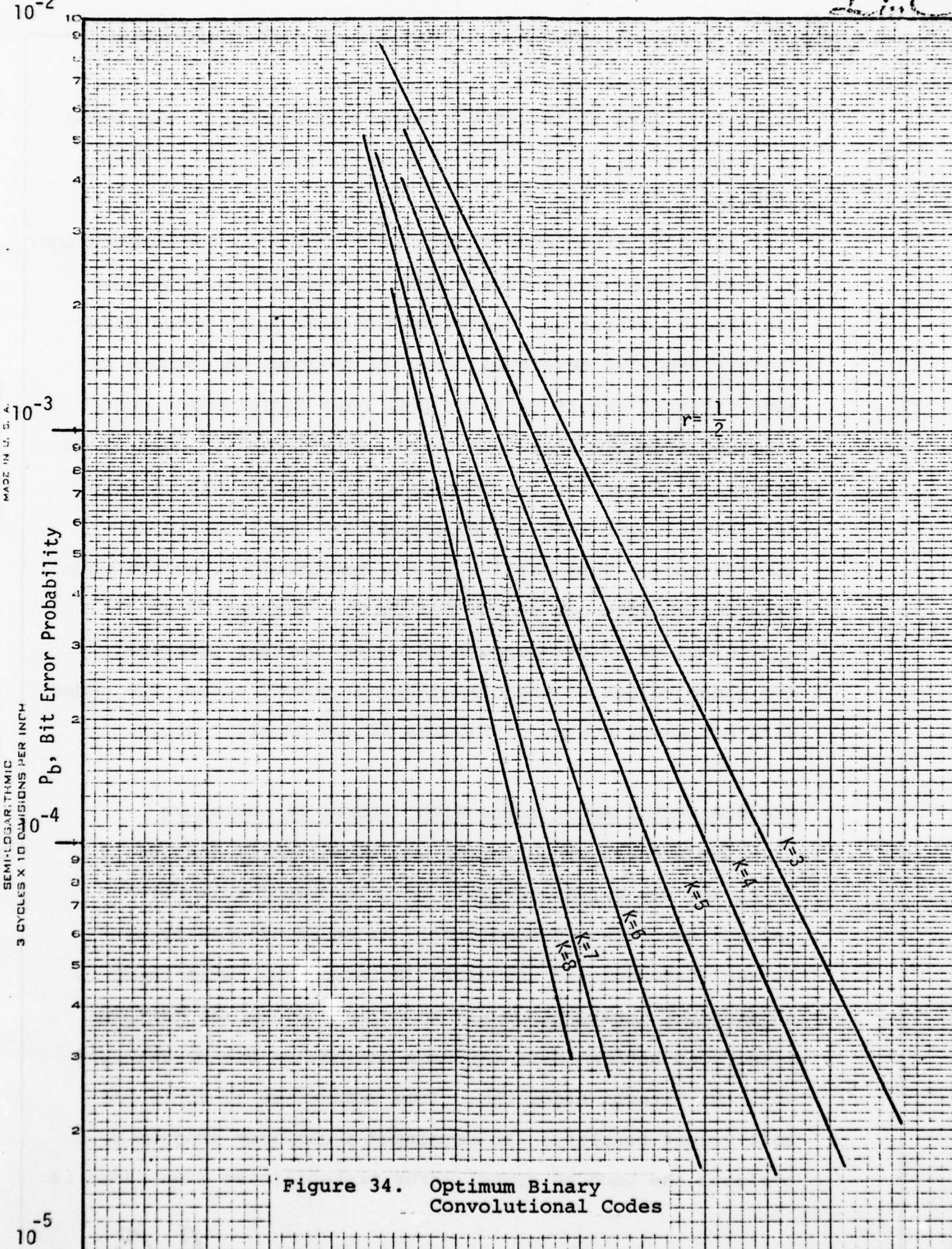


Figure 34. Optimum Binary Convolutional Codes

channels. Here the coded bit error probability is expressed in terms of the uncoded symbol error probability for BPSK signals.

Assuming interleavers and deinterleavers, the computational cutoff rates for channels with intersymbol interference can also be evaluated. Assuming the memoryless demodulator, in this study we developed computer programs to compute the computational cutoff rate for both hard decision and soft decision channels with intersymbol interference. Here it is natural to normalize the computational cutoff rate in bits per cahnnel symbol by the BT product of the intersymbol interference. This results in the computational cutoff rate measured in bits per second per Hertz. Figures 35 to 37 show examples of the outputs of these computer programs. For these values of the computational cutoff rates, the coded data bit error curves of Figures 32 and 33 still apply.

Uncoded Symbol Error Rates With Viterbi Demodulators

The uncoded symbol error probabilities of Figures 19 to 21 are for varying degrees of intersymbol interference using a memoryless demodulator. As shown originally by Forney (Reference 8) and Omura (Reference 9), when there is intersymbol interference and no uplink noise, the maximum likelihood uncoded data sequence estimation can be realized with the Viterbi algorithm. (See References 12 to 16 for more recent results.) We developed a computer program to evaluate the uncoded symbol error probabilities when there is

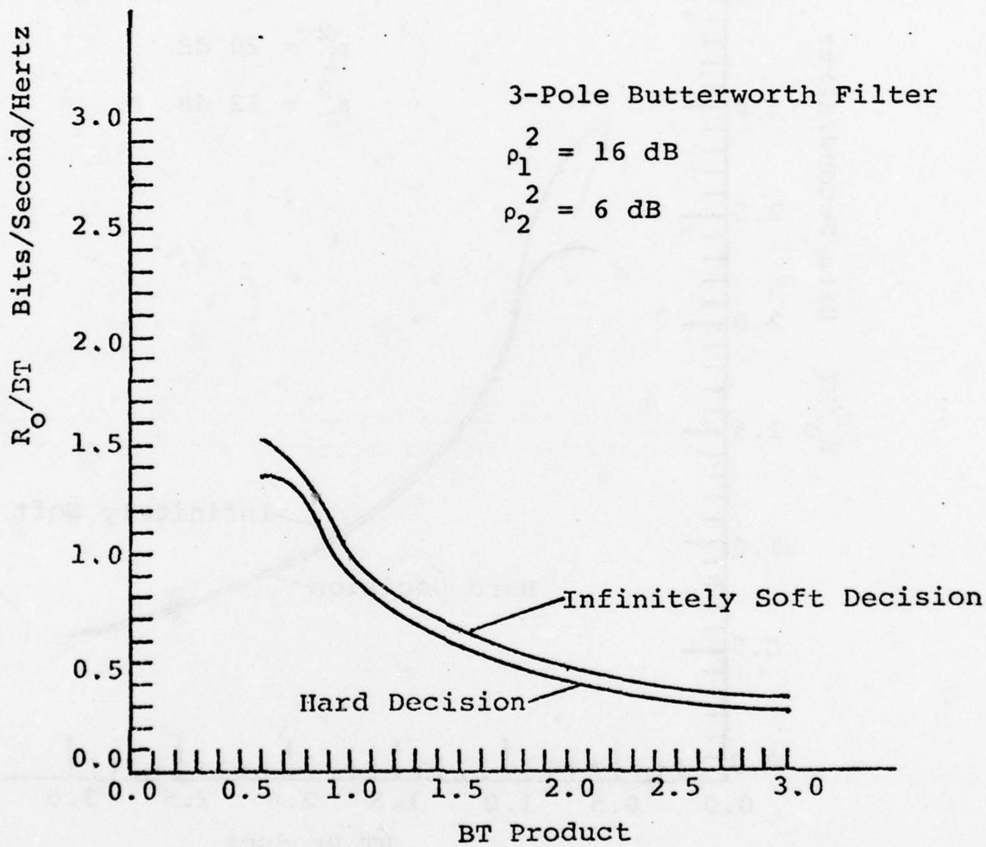


Figure 35. BPSK - Normalized Computational Cutoff Rate vs. BT Product: Memoryless Demodulator

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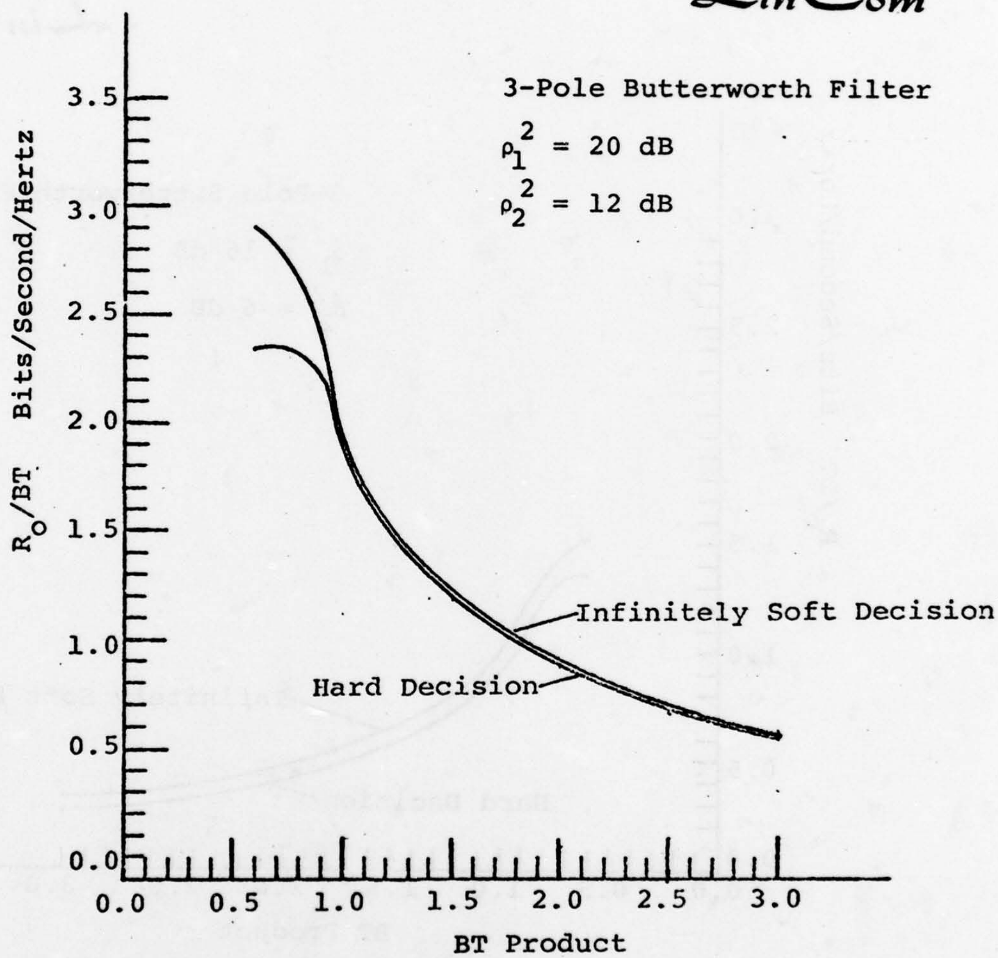

Figure 36. QPSK - Normalized Computational Cutoff Rate vs. BT Product: Memoryless Demodulator

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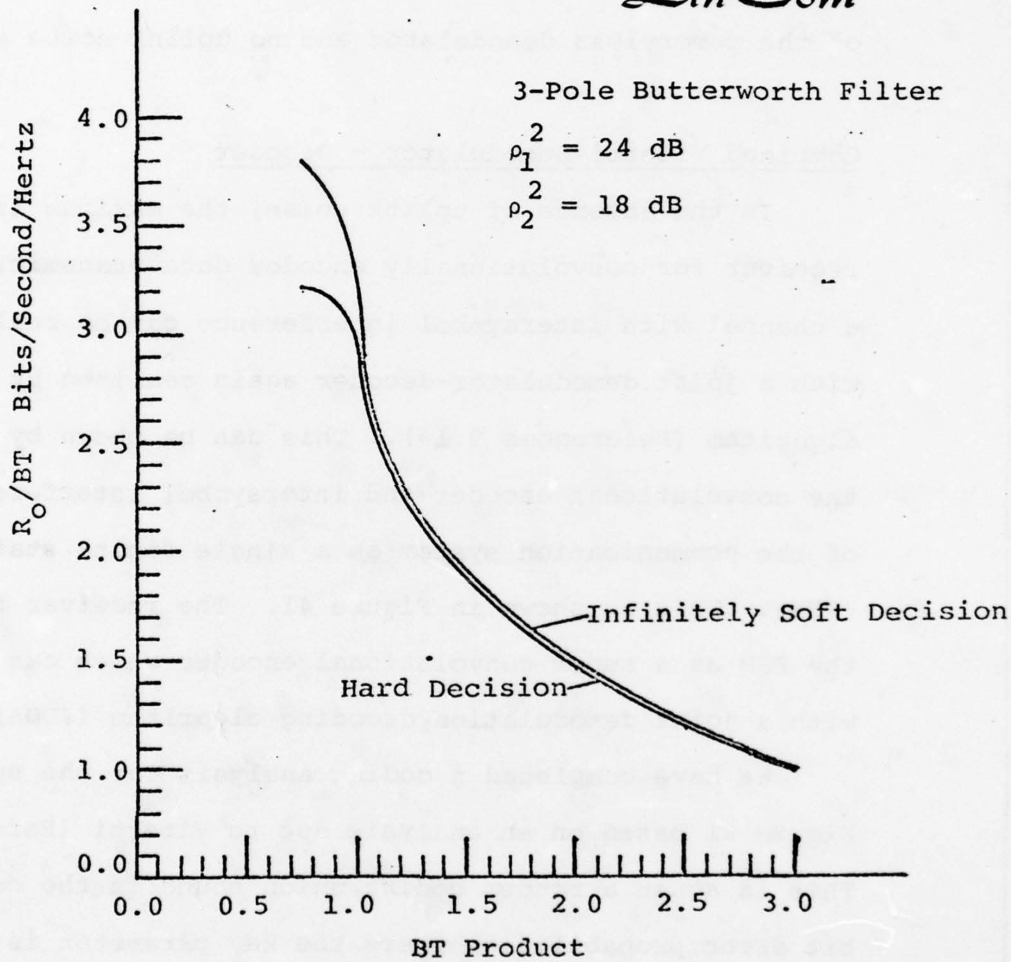

Figure 37. 8PSK - Normalized Computational Cutoff Rate vs. BT Product: Memoryless Demodulator

intersymbol interference and a Viterbi demodulator. This applies only to the case where there is no uplink noise. Figures 38 to 40 show the performance of the same system as in Figures 19 to 21 only with the Viterbi demodulator instead of the memoryless demodulator and no uplink noise assumed.

Combined Viterbi Demodulator - Decoder

In the absence of uplink noise, the maximum likelihood receiver for convolutionally encoded data transmitted over a channel with intersymbol interference can be realized with a joint demodulator-decoder again realized by a Viterbi algorithm (References 9,16). This can be shown by combining the convolutional encoder and intersymbol interference parts of the communication system as a single finite state machine (FSM). This is shown in Figure 41. The receiver then regards the FSM as a super convolutional encoder which can be decoded with a joint demodulation decoding algorithm (JDDA).

We have completed a coding analysis for the system of Figure 41 based on an analysis due to Viterbi (Reference 16). This is again a random coding union bound on the coded data bit error probabilities where the key parameter is the computational cutoff rate. Figures 42 to 44 show the results of a computer program that evaluates the normalized computational cutoff rates for the coded intersymbol interference system of Figure 41 with the joint demodulation decoding algorithm.

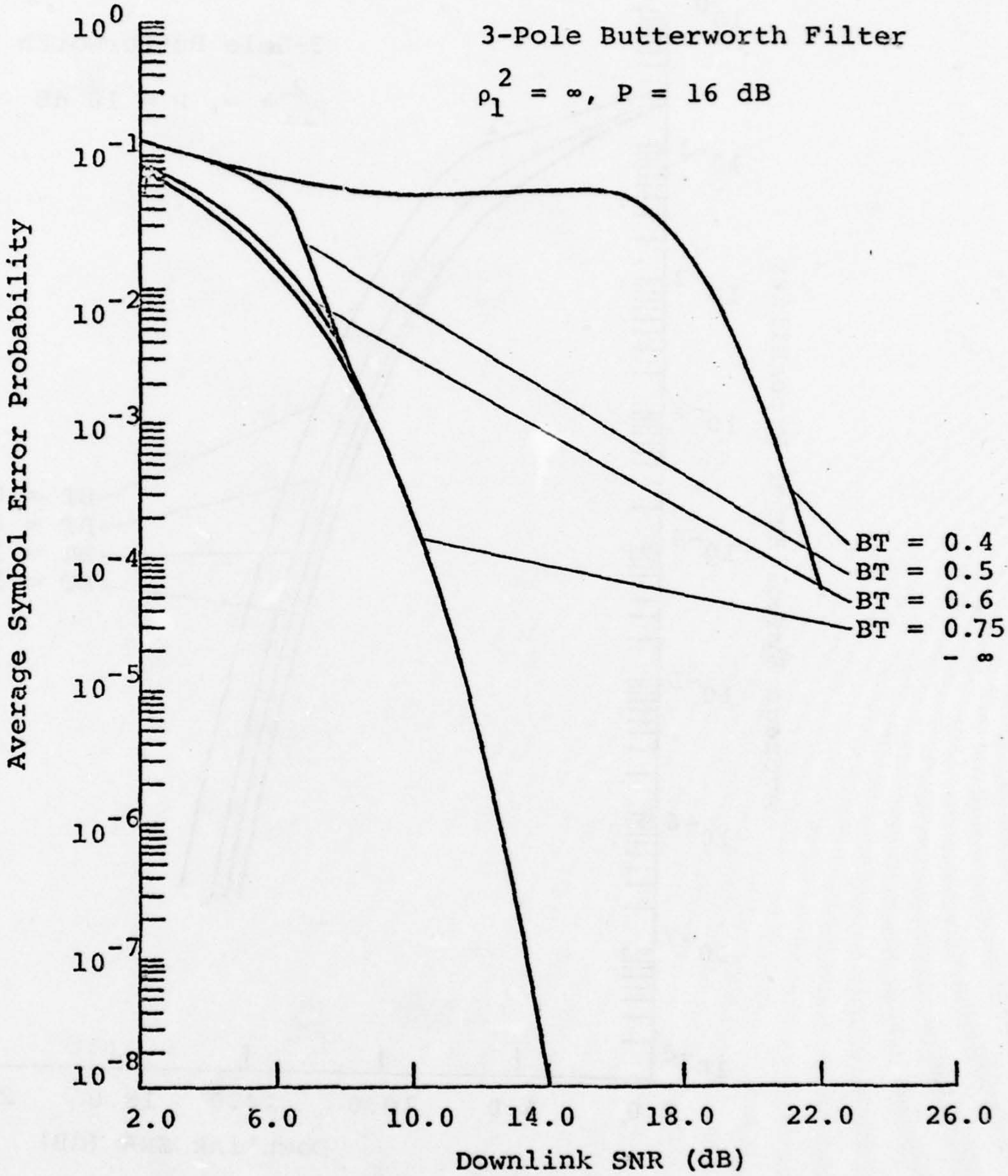

Figure 38. BPSK Average Symbol Error Probability vs. Downlink SNR: Viterbi Demodulator

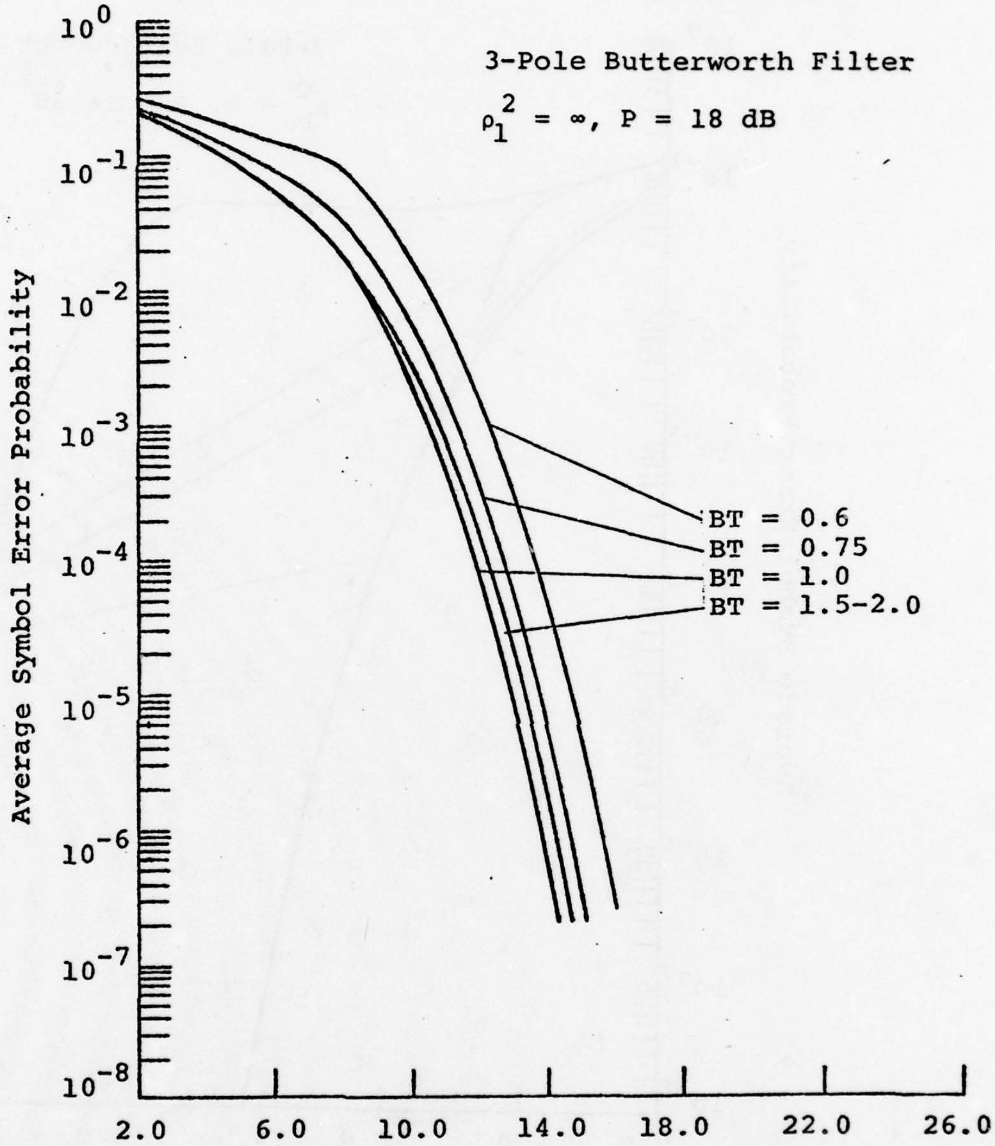

Figure 39. **QPSK Average Symbol Error Probability vs. *Downlink SNR:* Viterbi Demodulator**

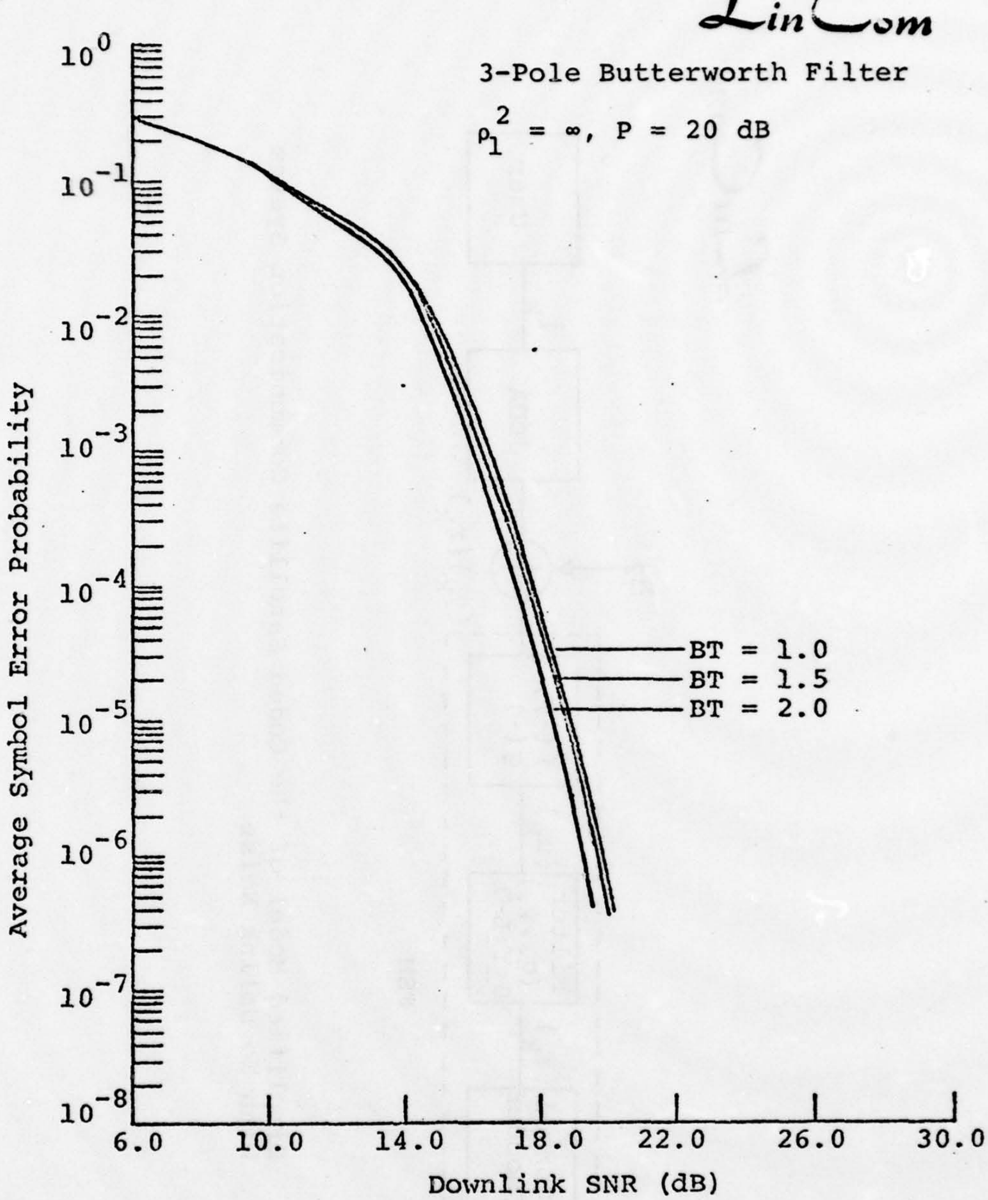

Figure 40. 8PSK Average Symbol Error Probability vs. Downlink SNR: Viterbi Demodulator

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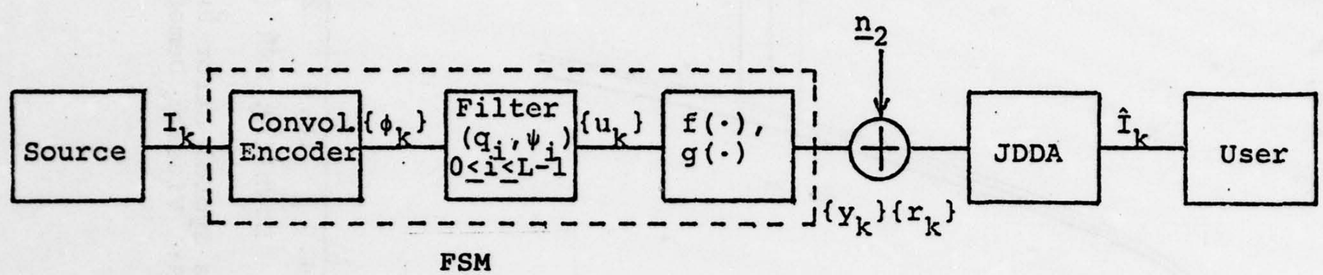

Figure 41. Simplified Model of the Coded Satellite Communication System with No Uplink Noise

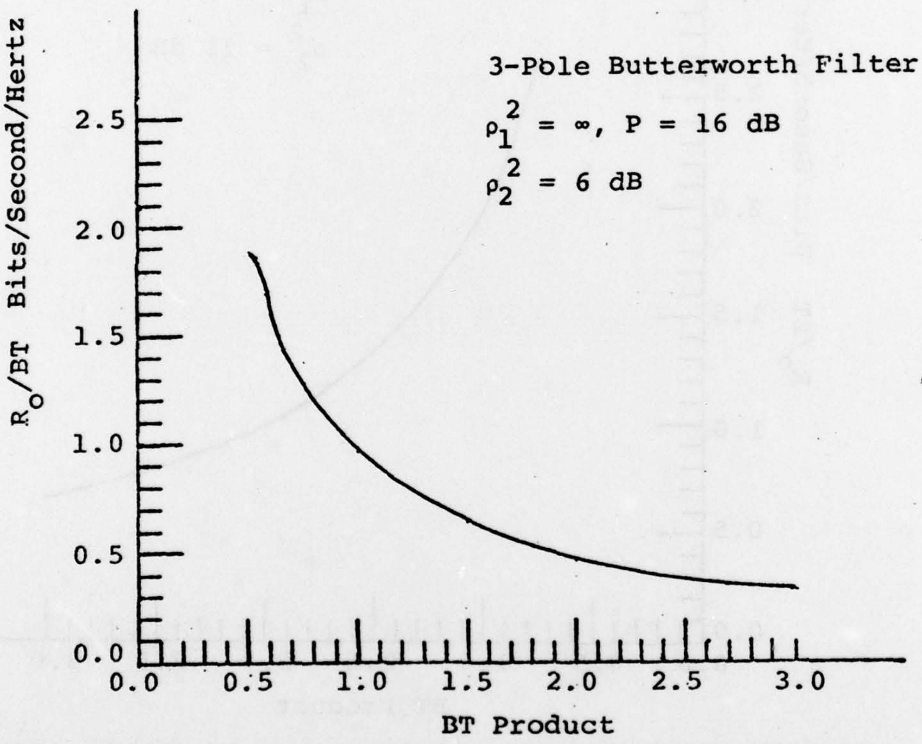

Figure 42. **BPSK Normalized Computational Cutoff Rate vs. VT Product: Joint Demodulation Decoding Algorithm**

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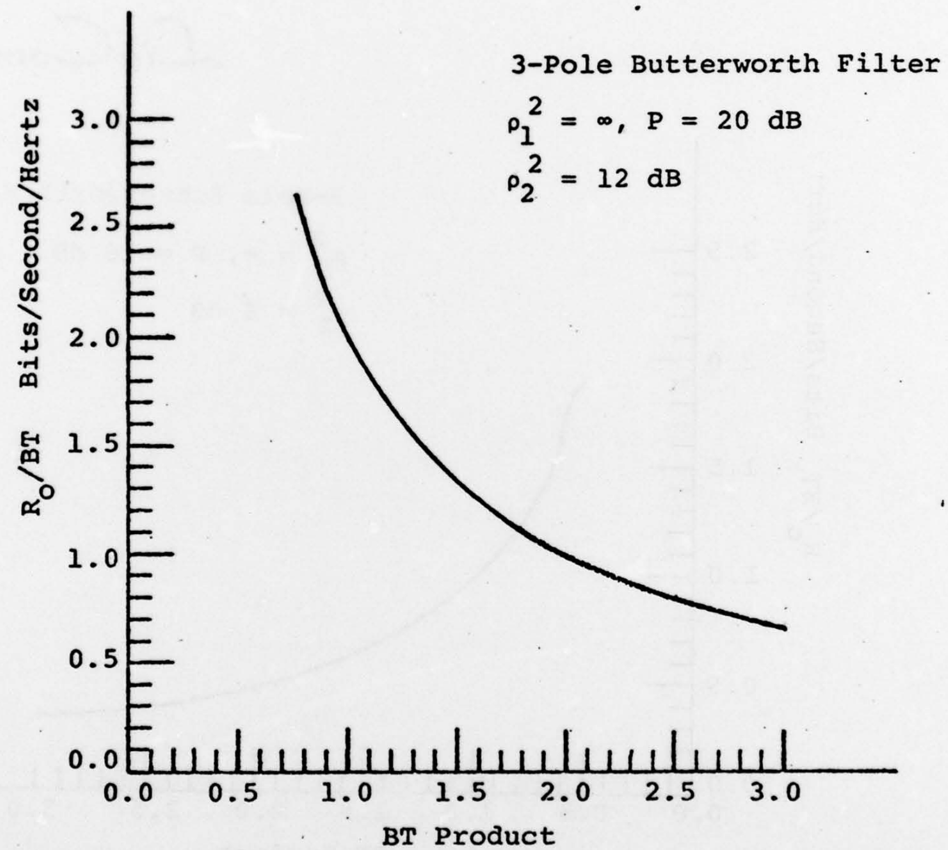


Figure 43. QPSK Normalized Computational Cutoff Rate vs. BT Product: Joint Demodulation Decoding Algorithm

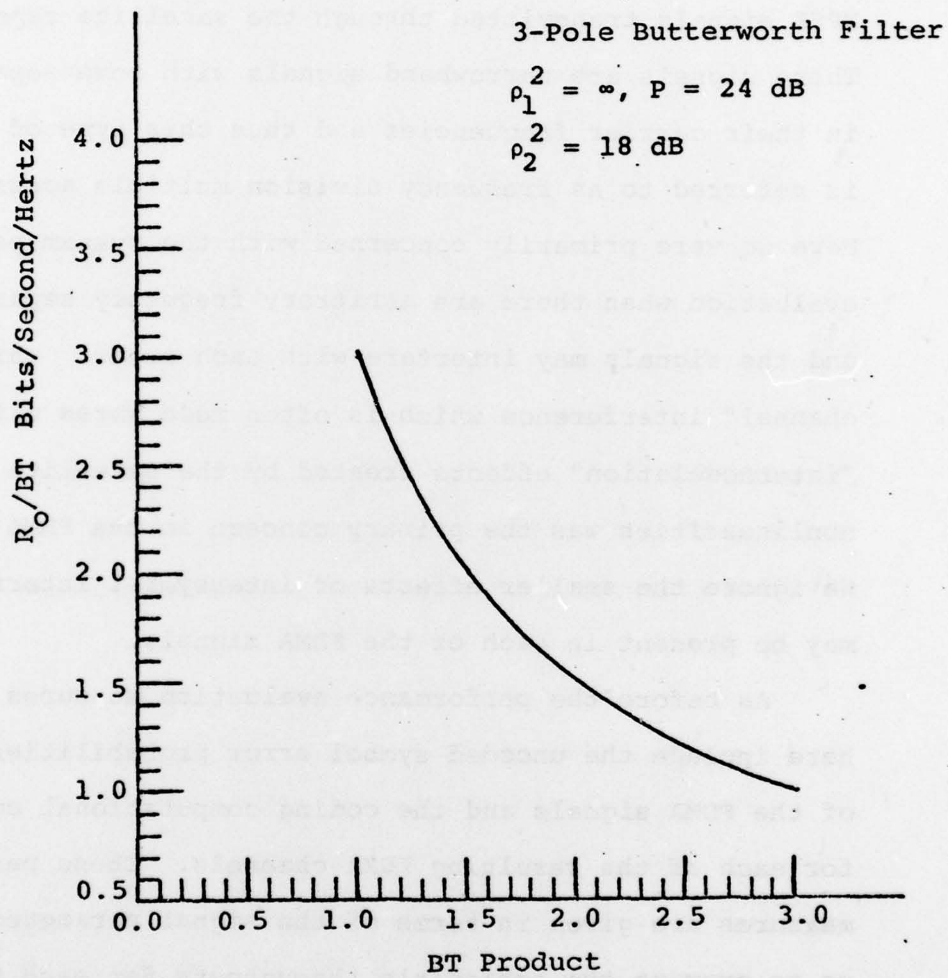


Figure 44. 8PSK Normalized Computational Cutoff Rate vs. BT Product: Joint Demodulation Decoding Algorithm

FDMA System Analysis

We extended the single signal results discussed up to this point to the case where there are multiple coherent MPSK signals transmitted through the satellite repeater. These signals are narrowband signals with some separation in their carrier frequencies and thus this type of signalling is referred to as frequency division multiple access (FDMA). Here we were primarily concerned with the system performance evaluation when there are arbitrary frequency separations and the signals may interfere with each other. This "co-channel" interference which is often made worse with the "intermodulation" effects created by the satellite repeater's nonlinearities was the primary concern in the FDMA analysis. We ignore the smaller effects of intersymbol interference that may be present in each of the FDMA signals.

As before the performance evaluation measures we used here include the uncoded symbol error probabilities for each of the FDMA signals and the coding computational cutoff rates for each of the resulting FDMA channels. These performance measures are given in terms of the signal parameters enabling us to examine the achievable throughputs for each FDMA channel as a function of these signal parameters. Signal frequency separations and baud times are among these parameters.

The basic approach to the analysis taken here is an extension of the moment approximation technique due to Krein (Reference 17) which has been recently extended and applied by Benedetto and Biglieri (Reference 18) and Yao and

Biglieri (Reference 19). This is in contrast to the approach based on computing intermodulation product terms at the output of the satellite nonlinearity.

In general this analysis assumes that there are L FDMA signals that are being transmitted through the satellite repeater which we modelled earlier. Aside from the fact that all L signals are coherent phase modulated signals, there are no common features among these signals. For example each of the L signals can have different modulations and baud times. In addition there is no assumed synchronization among the L users so that each signal has a phase and epoch time that is independent of the other signals. As a special case we can assume synchronization among the users.

Computer programs based on the moment approximation method were developed to evaluate both uncoded symbol error probabilities and computational cutoff rates for each of the FDMA signals and the coding channel created by each transmitter to receiver system. For each of the FDMA channels the same coding analysis based on the random coding union bounds still applies. Hence an overall modulation/coding tradeoff of the FDMA system can be done. Here there are, of course, more parameters to consider and a set of achievable data throughputs and a set of coded or uncoded data bit error rates. Figures 45 and 46 give an example of outputs of the computer program when there are L=3 FDMA signals.

Note that the curves given in Figs. 45 and 46 are obtained under the assumed FDMA signal conditions indicated in each figure. The nonlinearity of satellite repeaters is assumed to have the same TWT characteristics used previously for the study of single channel performance. The operating point of the TWT is 0 dB input backoff. As an illustration, the signal conditions for curve A can be interpreted as follows:

Channel 1:

Center frequency:	1.021 GHz
Bandwidth:	10 MHz
Modulation:	BPSK
Power sharing ratio: K_p	0.3
Uplink signal-to-noise ratio:	6 dB
Initial phase ψ_0:	0.0

Channel 2:

Center frequency	1.05 GHz
Bandwidth:	12.05 MHz
Modulation:	QPSK
Power sharing ratio: K_p	0.3
Uplink signal-to-noise ratio:	12.0 dB
Initial phase ψ_0:	0.0777

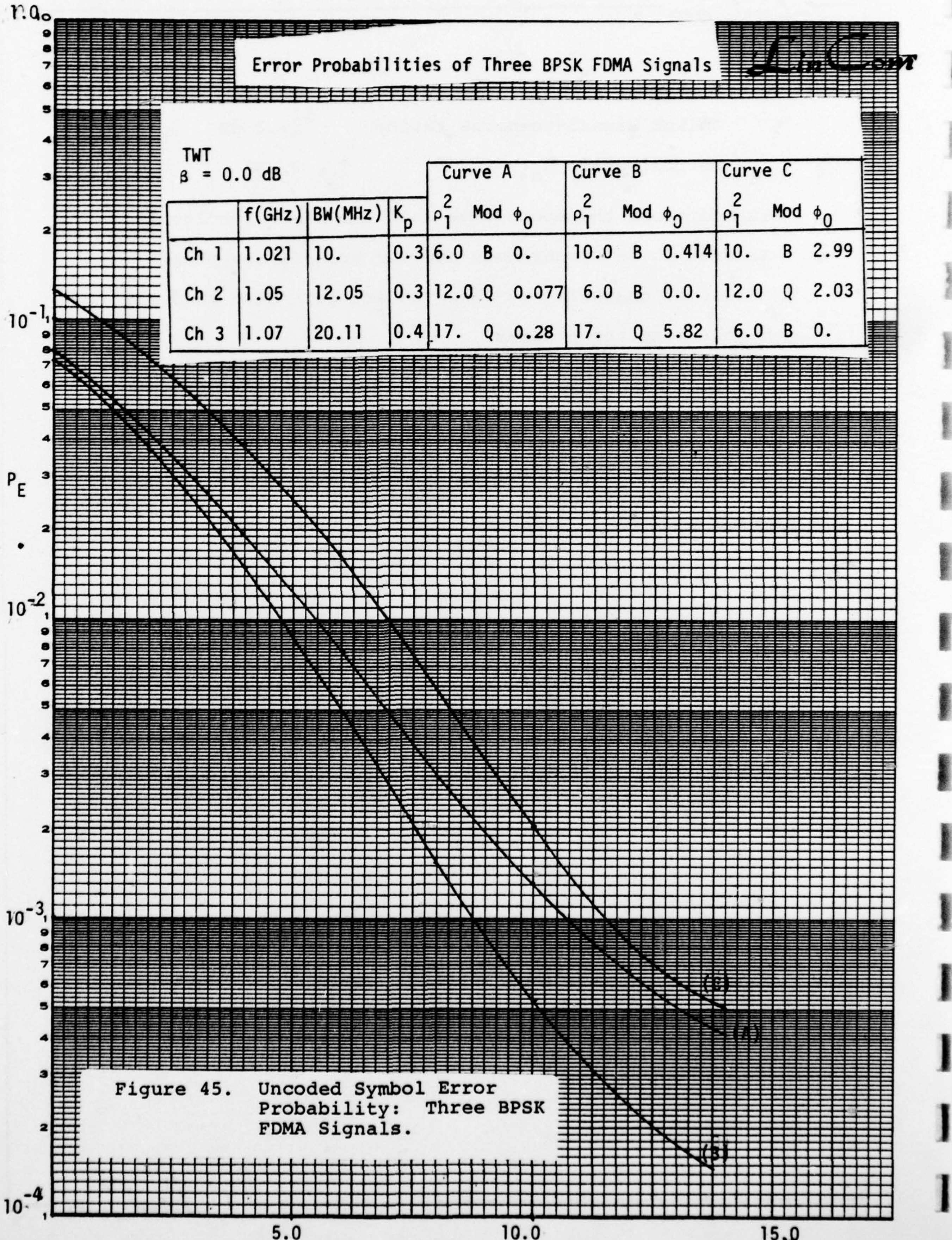
Channel 3:

Center frequency:	10.7 GHz
Bandwidth:	20.11 MHz
Modulation:	QPSK
Power sharing ratio: K_p	0.4

Uplink signal-to-noise ratio: 17.0 dB

Initial phase ψ_0: 0.28

In addition, the epoch time used for these results is assumed to be synchronous and the transmitted phase angles of channels not observed are generated randomly by the computer program.



	f(GHz)	BW(MHz)	K_p	Curve A ρ_1^2	Mod	ϕ_0	Curve B ρ_1^2	Mod	ϕ_0	Curve C ρ_1^2	Mod	ϕ_0
Ch 1	1.021	10.	0.3	6.0	B	0.	10.0	B	0.414	10.	B	2.99
Ch 2	1.05	12.05	0.3	12.0	Q	0.077	6.0	B	0.0.	12.0	Q	2.03
Ch 3	1.07	20.11	0.4	17.	Q	0.28	17.	Q	5.82	6.0	B	0.

Figure 45. Uncoded Symbol Error Probability: Three BPSK FDMA Signals.

R_0 Values: Three BPSK FDMA Signals

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TWT
β = 0.0 dB

	f(GHz)	BW(MHz)	K_p	Curve A ρ_1^2	Mod	ϕ_0	Curve B ρ_1^2	Mod	ϕ_0	Curve C ρ_1^2	Mod	ϕ_0
Ch 1	1.021	10.	0.3	6.0	B	0.	10.0	B	0.414	10.	B	2.99
Ch 2	1.05	12.05	0.3	12.0	Q	0.077	6.0	B	0.0.	12.0	Q	2.03
Ch 3	1.07	20.11	0.4	17.	Q	0.28	17.	Q	5.82	6.0	B	0.

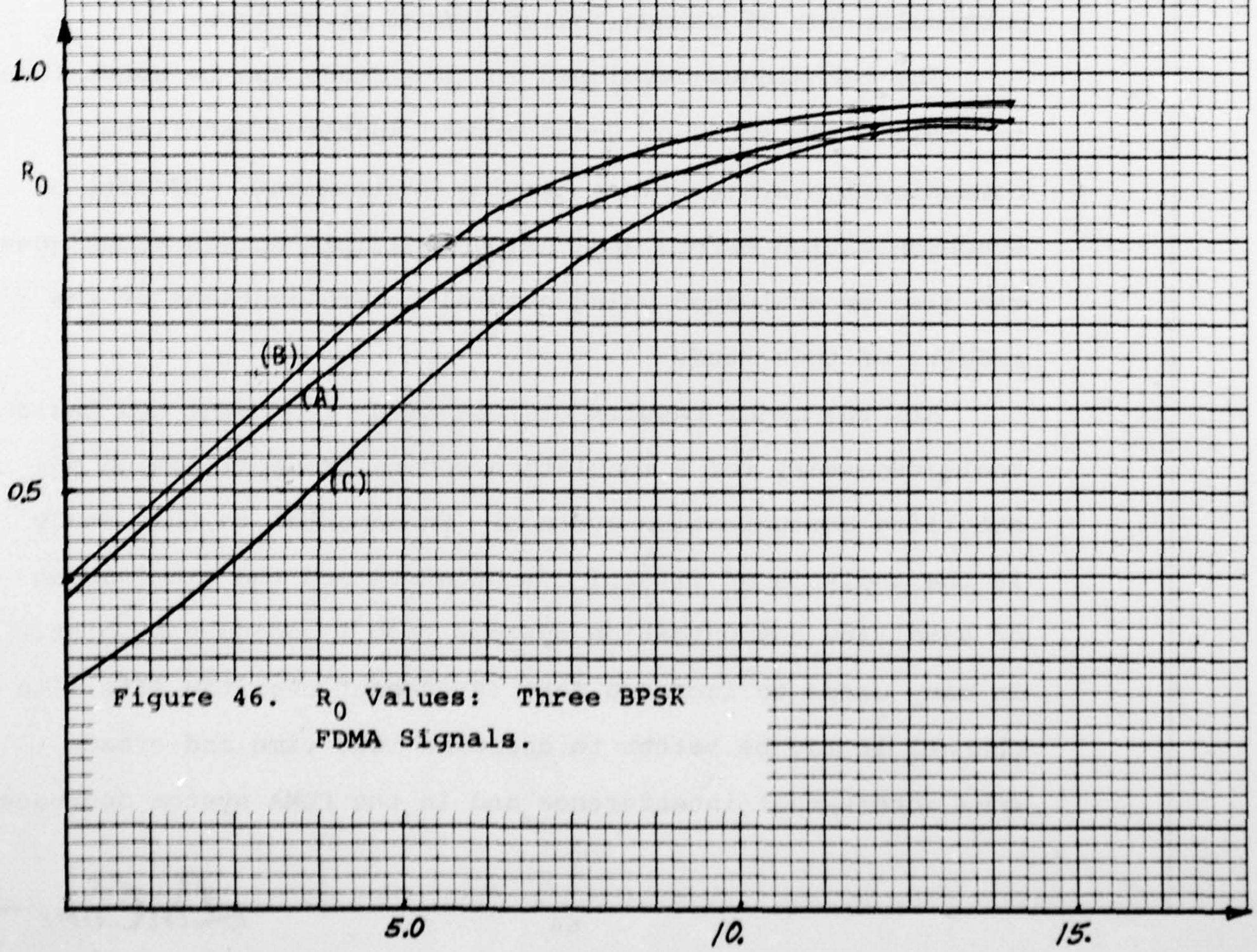

Figure 46. R_0 Values: Three BPSK FDMA Signals.

Downlink SNR (in dB)

6. CONCLUSIONS

The goals of this study have been achieved. New analytical results combined with new computational techniques have resulted in several computer programs that form powerful tools for the design and analysis of many satellite communication systems. For a given set of communication system parameters including limiters and TWT characteristics, a complete modulation, demodulation, and coding tradeoff can be done. For an illustration see the examples of Figures 2 to 5. Based on the criterion of maximum data throughput for a given data error rate we can determine the modulation, demodulation, and coding combination that is optimum for the particular set of communication system parameters.

The techniques developed in this study can be generalized to include the study of coded spread spectrum satellite communication systems in a jamming environment. Effects of synchronization errors and various multiple access techniques can also be evaluated using natural generalizations of the results of this study.

All the major results of this study represent new basic tools necessary for a modulation/coding tradeoff design of satellite communication systems. Fundamental to this study is the analysis of Viterbi demodulators and the examination of satellite communication systems from a coding viewpoint. In many cases to increase data throughput over the satellite channel it may be better to decrease baud time and create some intersymbol interference and in the FDMA system decrease

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frequency spacing to create some co-channel intermodulation effects. The degradation due to these interfering terms can then be handled by maximum likelihood receives and coding. For the uncoded case the data rates versus uncoded data error rates can be obtained directly from the computer programs developed here. With coding we assume an analysis based on the computational cutoff rates. These coding parameters can be evaluated with the computer programs of this study. To obtain the data rates versus coder data bit error probabilities we use Figures 32 and 33.

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